海洋生物の大回遊機構解明のための地磁気センサロガーの開発

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はしがき

近年のマイクロエレクトロニクスの急速な発展は、海洋生物の行動生態研究に画期的な研究手法を提供することとなった。現在、各種のマイクロデータロガーや超音波テレメトリー並びに人工衛星によるテレメトリーなどによって、海洋生物の遊泳水深、遊泳速度・加速度、経験水温、体内温度等が得られるようになってきている。また、我々の研究によって自由遊泳中の海洋生物の心拍数の計測も可能となった。

本研究においては、これらのセンサーに加えて、地磁気センサーを搭載したデータロガーを開発し、これにより海洋生物の三次元行動を測定しようとするものである。

本研究期間に地磁気センサーと加速度センサーを組み合わせた各種のプロトタイプを製作した。これらのプロトタイプを最初の段階はタイ国水産局（現　海洋沿岸資源局）傘下のウミガメ保護ステーションにある飼育池（約５ヘクタール）で実際のウミガメ（アオウミガメおよびタイマイ）に装着してデータを取得した。これらの実験結果を下にプロトタイプの改良を行い最終的にはアンダマン海におけるアオウミガメの重要な産卵地であるシミラン諸島フーヨン島において、実海域実験を行い、当初の目的である三次元の遊泳行動の再現に成功した。

本報告書には 4 カ年の機器開発及びフィールド研究によって得られた成果を下に執筆された修士論文、研究発表並びに技術資料を掲載した。

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No.	著者名	論文標題	雑誌名	巻・号	発行年	ページ
1	Nobuaki Arai, Mizuki Yoshida, Wataru Sakamoto, Yasushi Mitsunaga, Haruhiko Masuda and Mickmin Churuchinda	Development of new devices for marine biotelmetry: preliminary results from visual data storage tags and magnetic field sensor accelerometers attached to adult sea turtles	J.Adv.Mar.Sci.Tech.Soci.	8(1)	2003	15-23
2	Tohya Yasuda and Nobuaki Arai	International Conservation and Management of Straddling Stocks including Sea Turtles	The 3rd SEASTAR 2000 Workshop Proceedings	−	2003	83-86
3	荒井修亮	ウミガメを追いかける	岩波科学	73(1)	2003	48-52
4	Nobuaki Arai	The results of SEASTAR2000 and related projects in ASEAN countries	Proceedings of International Conference on Informatics Research for Development of Knowledge Society Infrastructure	−	2004	122-129
5	Tohya Yasuda, Nobuaki Arai, Hideji Tanaka, Kongkiat Kittiwattanawong, Haruhiko Masuda, Winai KlomOin and Wataru Sakamoto	Reconstrution of three-dimensional moving paths of green turtles by means of magneto-resiztive loggers	The 4th SEASTAR 2000 Workshop Proceedings	in press	2004	−
6	Tohya Yasuda, Kongkiat Kittiniwattanawong, Hideji Tanaka, Wataru Sakamoto, Haruhiko Masuda, Nobuaki Arai, Winai Klom-In	Spatial Diving Behavior of Sea Turtles using New Data Loggers	Proceedings of The 17th Symposium of the International Society	投稿中	−	−
7	安田十也・荒井修亮、Kongkiat Kittiniwattanawong、坂本亘、Winai Klom-In	アセアン諸国における水圏生物エコツーリズムの実現をめざしてⅠ－アンダマン海におけるアオウミガメの回遊生態－	平成15年度日本水産学会春季大会講演要旨集	口頭発表	2003	67
8	荒井修亮、坂本亘、光永靖	バイオテレメトリーによる水圏生物情報の取得と応用1－SEASTAR2000の成果と展望	平成16年度日本水産学会春季大会講演要旨集	口頭発表	2004	77
9	安田十也、杉原千哉子, Kongkiat Kittiwattanawong, Winai Klom-in, 坂本亘、荒井修亮	バイオテレメトリーによる水圏生物情報の取得と応用2－アルゴスデータから推定するアオウミガメの行動圏	平成16年度日本水産学会春季大会講演要旨集	口頭発表	2004	77
10	安田十也、田中秀二、三田村啓理、荒井修亮 Kongkiat Kittiwattanawong, Winai Klom-in, 坂本亘	バイオテレメトリーによる水圏生物情報の取得と応用3－シミラン諸島におけるアオウミガメの産卵時期	平成16年度日本水産学会春季大会講演要旨集	口頭発表	2004	77

研究成果による工業所有権の出願・取得状況

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研究発表

技術資料

Development of new devices for marine biotelemetry: preliminary results from visual data storage tags and magnetic field sensor accelerometers attached to adult sea turtles

Development of new devices for marine biotelemetry: preliminary results from visual data storage tags and magnetic field sensor accelerometers attached to adult sea turtles

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Abstract

We have challenged to adopt several micro-electronic devices for marine biotelemetry. The devices included data storage tags, ultrasonic tags and satellite platform transmitter terminals (PTTs). In this paper, we introduced brand-new devices for marine biotelemetry including a magnetic field sensor accelerometer tag (MR tag) and a visual data storage tag (CCD tag). We performed the first trials of the proto-type of the brand-new tags attached to adult sea turtles in Thailand and discussed feasibilities of the devices for biotelemetry.

Keywords:
data storage tag, CCD, MR sensor, accelerometer, biotelemetry

Introduction

Due to drastic development of microelectronics, very sophisticated devices to measure behavior of marine lives are available. We challenged to adopt several new microelectronic devices in marine biology. The devices included small data storage tags, ultrasonic tags, and satellite platform transmitter terminals (PTTs) for red sea breams (Mitsunaga *et al.*, 1999), Adelie penguins *Pygoscelis adeliae* (unpubl. results), the Lake Biwa catfishes *Silurus biwaensis* (Takai *et al.*, 1997), black rockfishes *Sebastes inermis* (Arai *et al.*, submitted), loggerhead turtles *Caretta caretta* (Sakamoto *et al.*, 1997), and green turtles *Chelonia mydas* (Arai *et al.*, 2001). These techniques were very useful to understand the correlation between environmental factors and animal behavior. Based on the successful results, we initiated the development of two types of new marine biotelemetry devices. One is a visual data storage tag and the other is a magnetic field sensor accelerometer tag. In this paper, the preliminary results of the tests were introduced.

Materials and methods

The visual data storage tag was installed with a complementary metal-oxide-silicon charge-coupled device (CMOS CCD) that took 100 black-and-white pictures with 28000 pixels and

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stored them in a 1 mega-byte flush memory. The dimension of the tag is 92 x 40 x 28 mm^3, weighed ca. 200g in air and ca. 18g in water. It has an IrDA interface to transfer pictures to a personal computer. A prototype model has capacity to 100 m pressure and was timer-controlled to take pictures every one-hour. A lithium dry cell (CR2, 800mAh) provided enough currents for taking over 80 pictures.The magnetic field sensor accelerometer has a magneto-resistive effect (MR) sensor and three accelerometers in it. The MR sensor detects 3D magnetic field to transform into 3D direction data. All the signals of the MR sensors and the accelerometers were converted by A/D converter to 12-bit digital data controlled by a microprocessor inside the tag. The dimension is 54 mmϕ x 178 mm with ca. 1500g in the air and ca. 1000g in water. Two lithium dry cells (3B24TC x 2, 4000mAh) were equipped to provide ca. 65 mA for over 60 h. We conducted the first field tests of these tags attached to sea turtles in Thailand.

Our final goal is to develop new tag types applicable to fish tracking. However, the prototypes of the tags were too large to be attached on fish. Therefore, we conducted the field test of the tags using adult sea turtles in the Sea Turtle Conservation Station belonging to the Department of Fisheries of Thai government. The Station was located at the Mannai Island in the Gulf of Thailand about 200 km eastward far from Bangkok. The station was founded in 1972 and was the center for the sea turtle research in the Gulf of Thailand.

We tested two visual data storage tags (CCD tags) and two magnetic field sensor accelerometers (MR tags) attached to two adult hawksbill turtles *Eretmochelys imbrieata* and a green turtle *Chelonia mydas* **(Table 1)**. We attached the MR tags using polyethylene pedestals which bottom were sharpened for the shape of sea turtle carapaces. We glued the pedestals on the back of the sea turtles with epoxy resin. The MR tags were bound with some cable-ties. On the other hand the CCD tags were attached with both-sides adhesive tape **(Figs.1 and 2).**

Table 1.
Body weight (BW) and carved carapace length (CCL) of sample sea turtles attached with MR tangs (MR) and CCD tags (CCD).

Sample No.*	BW(kg)	CCL(cm)	Tag type
H3	65	83	MR
H4	50	76	CCD
G3	57	80	MR+CCD

* H3, H4: hawksbill turtles, G3: green turtle. All turtles were females.

The sampling rates of the MR tags were every 50 ms. The CCD tags took pictures every 1

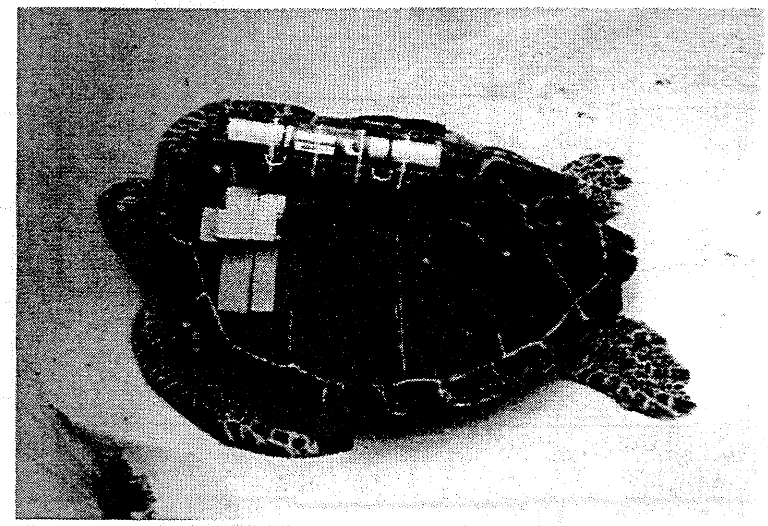

Fig. 1 A sample green sea turtle with a MR tag and a CCD tag. The upper tag is a MR tag and the lower tag is a CCD tag.

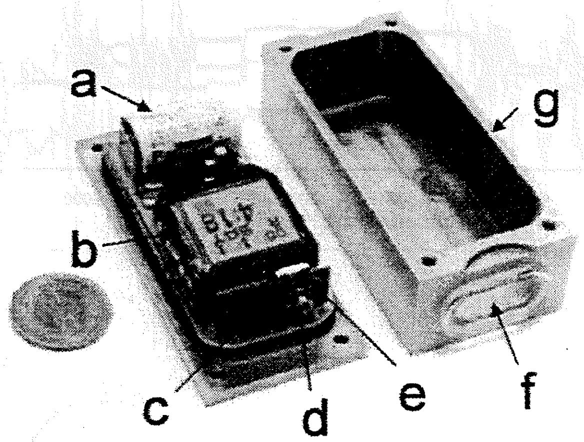

Fig. 2 A photo of a CCD tag; a: a lithium dry cell (CR2), b: a controller, c: a lens, d: a CdS, e: an IrDA interface, f: a window and g: a pressure-resistant case.

h. We released the sample turtles in a seawater pond that was a rectangle ca. 200 m x 40 m with several meters depth at 12:40 on 13 March 2001 and recovered them at 13:20 on 15 March 2001. We also took pictures under water every 7 minutes using an underwater digital camera installed one meter below the surface.

The two MR tags recorded continuous data for 48 hours 50 minutes. The data included 3D magnetic field and 3D acceleration every 50 ms. 3D means surging (X), swaying (Y), and pitching (Z) directions **(Fig.3)**. The sensor signals were

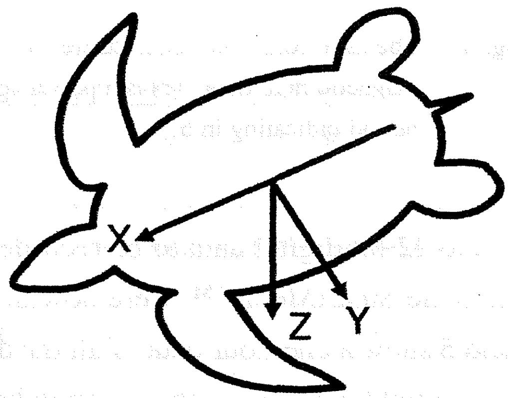

Fig. 3 The directions of 3D acceleration and magnetic field data.

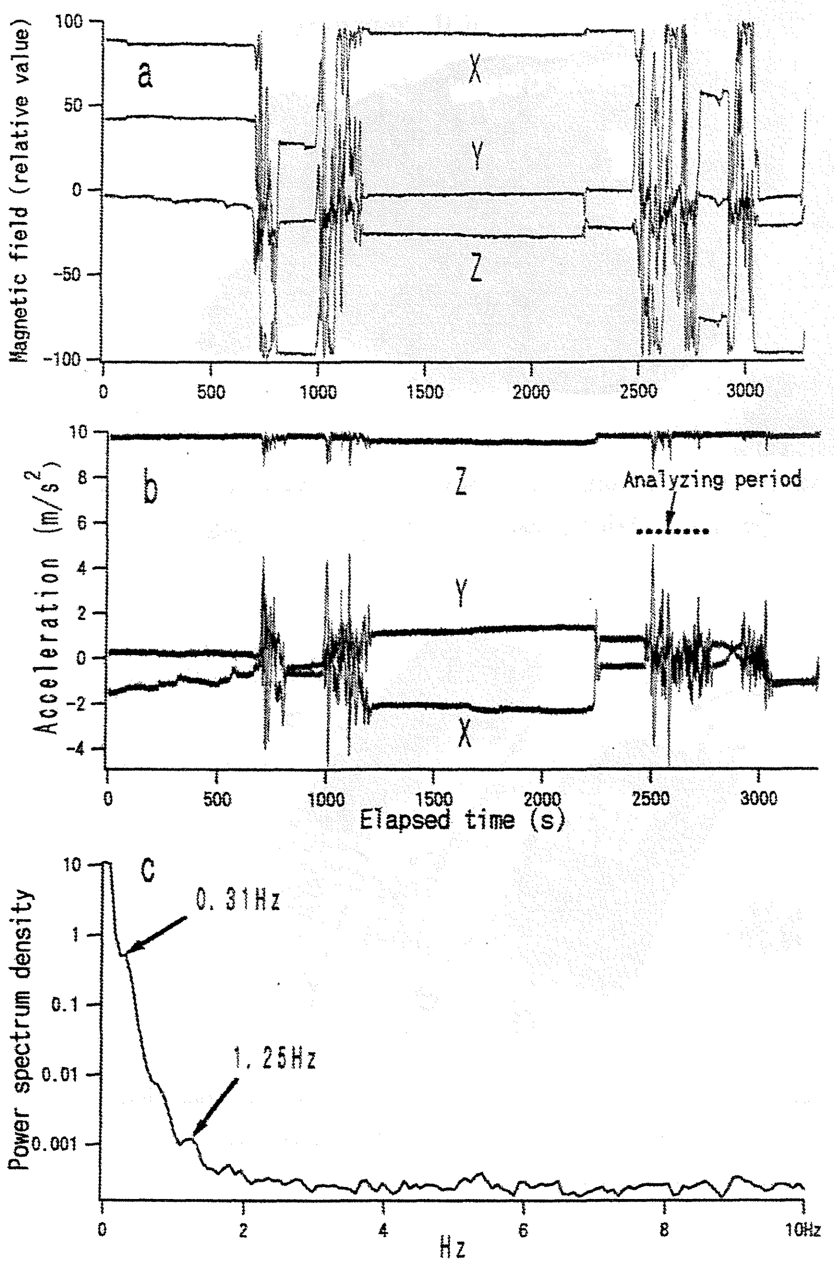

Fig. 4 The data from a hawksbill turtle (H3). (a, b) indicates one-hour data of 3D acceleration and magnetic field data . (c) is a power spectrum density of the X acceleration in the analyzing period indicating in b.

converted to 12-bit digital data to be recorded in a 64-megabyte SmartMedia™ inside the tag. The data in the SmartMedia™ were downloaded in a personal computer after the experiments. **Figs.4 and 5** show a one-hour data of all the data logged in the MR tags. **Figs. 4a and 5a** indicate 3D magnetic field data. Figs.4b and 5b indicate 3D acceleration data. The magnetic field data were normalized ranging from -100 to 100.

We calculated a approximate direction (θ , degree) of the turtles using X and Y horizontal magnetic field data as follows;

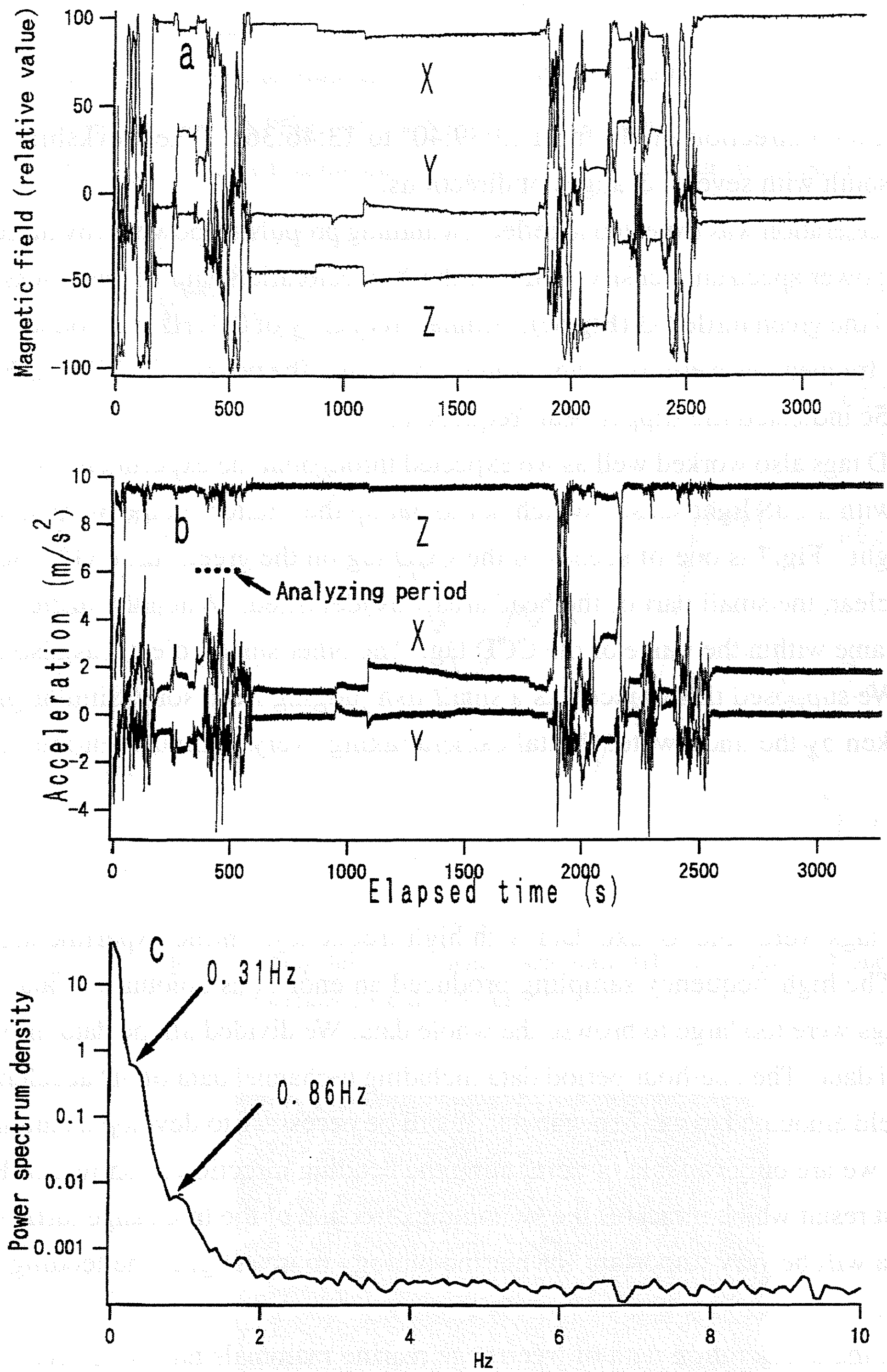

Fig. 5 The data from a green turtle (G3). (a, b) indicates one-hour data of 3D acceleration and magnetic field data . (c) is a power spectrum density of the X acceleration in the analyzing period indicating in b.

θ = 180 - arctan(Y/X) (X<0)

θ = - arctan(Y/X) (X>0, Y<0)

θ = 360 - arctan(Y/X) (X>0, Y>0)

θ = 90 (X=0, Y<0)

θ = 270 (X=0, Y>0).

Results

Fig.6 shows a direction of H3 from 13:39:40" to 13:46:36". The hawksbill turtle was moving to the south with several changes of directions.

The X acceleration was expected to reflect swimming propulsion powered by turtle flippers. We calculated power spectrum density (PSD) of the X acceleration data of the hawksbill turtle H3 **(Fig.4c)** and the green turtle G3 **(Fig.5c)**. Similar frequency of 0.31Hz was found in the both spectra. These frequencies were forced by water vibration. The peaks of 1.25Hz in **Fig.4c** and 0.86Hz in **Fig.5c** indicated the flipper beat frequencies.

Two CCD tags also worked well as we expected throughout the experiment. The CCD tag was equipped with a CdS light sensor switch not to put up the shutters in the night since the tag had no flush light. **Fig.7** is one of scenes of the CCD tag on the green turtle G3. Besides the scene was not clear, the small part of the head area was identified. When the turtle looked up, her own head came within the range of the CCD tag. The other small object was also identified in the scene. We supposed this object was a small fish judging from some similar pictures of small fishes taken by the underwater digital camera taking every 7 minutes in the fixed point continuously.

Discussion

The MR tags were able to take data with high frequency. In the experiments, we took every 50 ms. The high frequency sampling produced an enormous amount of data. The data from the MR tags were too large to browse the whole data. We divided all the data into 44-piece one-hour period data. The one-hour period data including 6-channel data of 3D acceleration and 3D magnetic field amounted to ca. 7-megabyte. It will be necessary to develop a data-analyzing tool. Although we are only capable of computing the heading direction as shown in **Fig.6**, the figure is the first result which indicates the swimming direction of the free-range turtle under the water. The data will be very important for marine biology to investigate the feeding behavior under the water.

Recently, the acceleration data of free-range marine mammals has been investigated by accelerometers including penguins (Yoda *et al.*, 1999, 2001; Arai *et al.*, 2000) and seals (Davis *et al.*, 1999; William *et al.*, 2000). Our intention is finally to combine the acceleration data with the direction of the magnetic field data to estimate a 3D position. The appropriate procedures of integration of the acceleration data are under development now.Regarding the PSD of the X acceleration, we found interesting frequencies. In the PSD of both the hawksbill turtle and the green turtle, the same frequency 0.31Hz was found. We supposed the frequency is vibration of the seawater in the pond. The other frequencies 1.25Hz in the hawksbill turtle (H3) and 0.86Hz in the green turtle (G3) were also detected. Judging from videotape, these frequencies indicate the turtle flipper frequencies.

Generally speaking, visual data are very exciting and useful for all the researchers. Davis *et al.* (1999) reported hunting behavior of Weddell seals beneath the Antarctic fast ice using a small video system attached on their backs. They concluded that the vision is important for

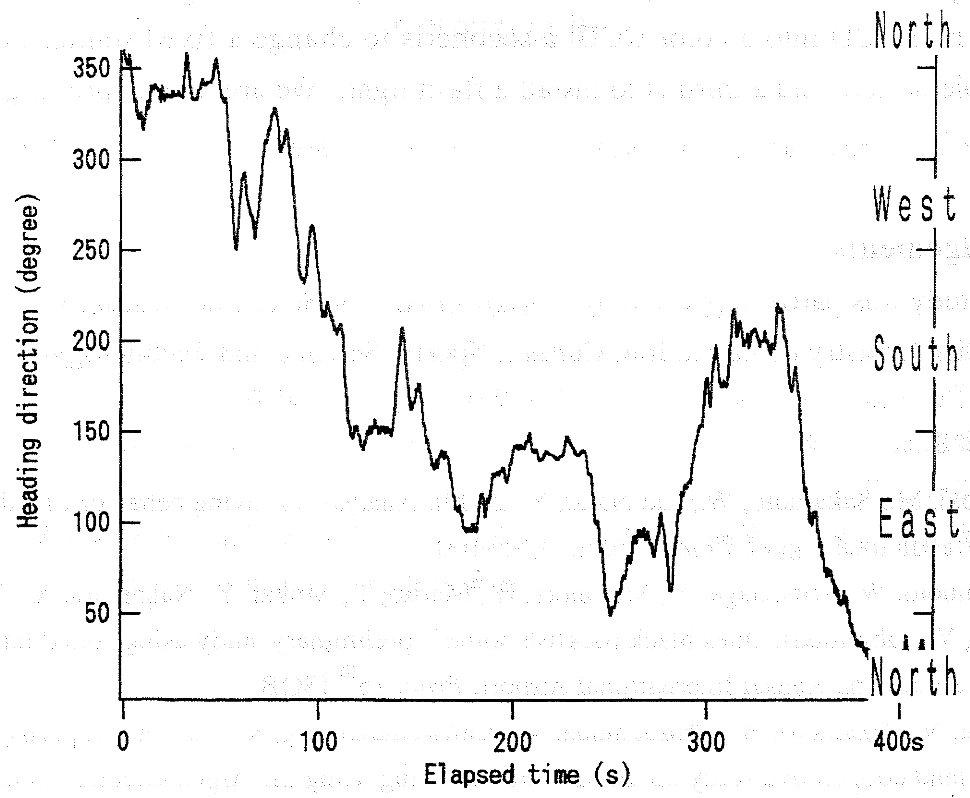

Fig. 6 Heading direction of a hawksbill turtle (H3) computed by X and Y magnetic field data for ca. 412 s.

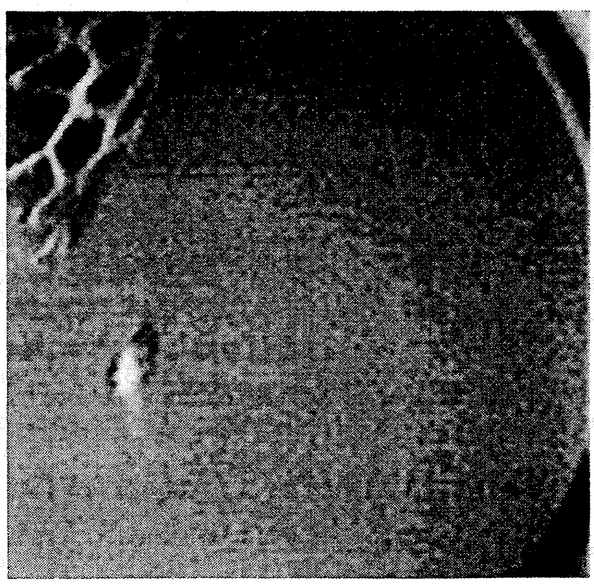

Fig. 7 One scene of the CCD tag on the green turtle (G3). The small part of the head and a small fish were identified in this picture. Objects at the upper right and the lower right were the window frame of the CCD tag.

hunting in Weddell seals. We agree in this conclusion but we had no small and smart devices to be attached on the smaller mammals. Our prototype is relatively small and light enough to be attached on the sea turtles; the weight of the CCD tag is only 0.04% of the body weight of the smallest sample sea turtle **(Table 1)**. There are several points to improve; one is to change a black-and-white CCD into a color CCD; a second is to change a fixed shutter period into a programmable period; and a third is to install a flash light. We are now improving all of them step-by-step.

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海洋生物バイオテレメトリーのための新しい装置の開発：ウミガメ成体に装着した画像データ標識と地磁気センサー加速度計による予備的な結果

荒井修亮[1]、吉田瑞紀[1]、坂本亘[2]、光永靖[3]、益田春比古[4]、
ミクミン・チャルチンダ[5]

和文要旨

我々は、海洋生物のバイオテレメトリー研究に様々なマイクロエレクトロニクス機器を使用してきた。例えば、データ蓄積標識、超音波標識ならびに人工衛星送信端末(PTT)などである。本論文では、海洋生物のバイオテレメトリー研究に資する、全く新しい地磁気センサー加速度計(MRタグ)および画像データタグ(CCDタグ)について紹介する。これらのプロトタイプの最初の海域実験をタイ国においてウミガメ成体に装着して実施し、得られたデータからこれらのバイオテレメトリー機器の可能性を議論した。

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Master Thesis

Conservation and management of straddling stocks

- Case study on green turtles in the Andaman Sea -

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February 6, 2004

Conservation and Management of straddling stocks
- Case study on green turtles in the Andaman Sea -

Contents

ストラドリングストックの保全管理
― アンダマン海に生息するアオウミガメ ―

安田　十也

要旨

ストラドリングストックとは、複数国の排他的経済水域および公海に跨り分布する生物資源を指す。国連海洋法条約では、本生物資源の保全管理について地域機関の役割を強めるように規定しており、各地域機関では科学データを基に関係国間のコンセンサス方式により決定されている。全種がワシントン条約の附属書Iに記載されているウミガメは、数百キロから数千キロに及ぶ回遊を行う動物として知られている。ウミガメは、漁業による混獲が個体数減少の一因であるといわれている。ウミガメの生態に基づいた漁業との共存策の考案が求められているが、生態的知見が極めて少ないことが問題となっている。本研究では、アンダマン海に生息するアオウミガメ（*Chelonia mydas*）をモデルに、本種の行動を記録するバイオテレメトリーシステムを構築した。得られた結果より、本種の生息地利用を把握し、合理的な保護区域の設定について検討することを目的とした。

1章では、タイ国との共同研究プロジェクトであるSEASTAR2000について述べる。2000年よりタイ国政府の要請を受けて、京都大学がウミガメの生態研究を共同で開始している。共同研究のワークショップが毎年開催され、ASEAN諸国をはじめ10カ国以上の研究者が参加している。本プロジェクトの課題として、垂直方向の行動が考慮されていないことや、アンダマン海側の個体群についても追跡が必要であること等があげられている。

2章では、調査地と対象個体について報告する。本研究では、アンダマン海タイ国フーヨン島においてアオウミガメの雌成体を対象に研究を行った。ウミガメ類の産卵は、地域によって決まった時期に固執して行われることが知られている。しかしながら、フーヨン島は1年を通じてアオウミガメの産卵が観察される。そこで標識調査を行った結果、アオウミガメの産卵期間は、個体間変異が環境制約により変化するが、産卵期を固執するという形質は環境制約に依存しないことを明らかにした。この形質が、世界各地の繁殖場で産卵期に地域変異がある理由と考えられる。本調査地は、年中産卵が見られるため研究に適切な地域であると同時に、生態学的にも貴重な個体群が生息する地域であることが示された。

3章では、衛星テレメトリーを利用したアンダマン海に生息するアオウミガメの回遊経路や生息地利用についての研究を報告する。2001年から2003年までに、タイ国フーヨン島で産卵したアオウミガメのべ9個体の回遊経路をアルゴスシステムにより追跡した。アルゴスシステムは、極軌道衛星NOAAを利用した位置観測システムである。追跡結果より、フーヨン島で産卵したアオウミガメの回遊経路は、産卵期およびそれ以降で行動様式が異なった。産卵期は産卵場周辺で生息したが、それ以降の回遊経路はインド国アンダマン諸島およびタイ国プラトン島の2パターンあることが明らかになった。追跡個体は目的地に

到着すると、その場所に滞在したため、アンダマン諸島およびプラトン島沿岸は、追跡個体の採餌場であることが示唆された。得られた位置情報より、本種の行動圏を算出した。産卵期の行動圏は、コアエリアが産卵場より６ｋｍ以内にあった。採餌期の行動圏は、コアエリアが沿岸より 5km 以内に存在していた。アオウミガメは、産卵期間中は採餌を行わないためトラベリングコストを抑えた行動をとったと考えられる。採餌期間は、餌となる海草類が分布する有光層に分布域が集中していた。産卵期および採餌期どちらも、沿岸より 6km の海域がアオウミガメにとって、重要な生息地であると考えられる。

3 章では、ウミガメのマクロな行動を追跡し、行動圏を推定した。しかし、ウミガメは 3 次元で移動する動物であり、水中での行動様式を無視することができない。また、アルゴスシステムはウミガメが呼吸のため浮上した時のみ衛星との通信が可能となるため、微細なスケールで行動を記録することができない。そこで 4 章では、ウミガメの海中での行動を三次元で再現することに試みた。地磁気加速度データロガーを開発し、地磁気データからウミガメの体軸方位を、加速度データから体軸角度をそれぞれ算出した。また、速度データロガーを用いて、遊泳速度を記録した。体軸方位・体軸角度・遊泳速度より、ウミガメの移動ベクトルを 1 秒間隔で計算し、遊泳経路を三次元で再現した。測器は体軸と平行に装着することが不可能なため、垂直移動に関して大きな誤差が生じた。そこで体軸角度の誤差を深度の時系列プロファイルを用いて補正した。水平移動は海流など環境要因の影響を強く受けていると考えられる。

Conservation and management of straddling stocks

- Case study on green turtles in the Andaman Sea -

Tohya Yasuda

Abstract

United Nation Convention of the Law of the Sea had told that the role of regional agencies should be enhanced to manage straddling stocks occurring within the exclusive economic zones of two or more coastal States or both within the exclusive economic zone and in an area beyond and adjacent to it. The straddling stocks, therefore, are managed by consensus among the relational countries, and a program of management is determined based on scientific data. All sea turtle species, are listed CITES appendix I , and known to migrate more than several hundreds or thousands kilometers. The one of threat for sea turtles is incidental catch by fisheries. Although conservation and management programs of sea should be developed, little ecological information is able to develop them. Therefore, in this study, the biotelemetry system, enable to record the animal movement remotely, was developed and applied to the green turtle, *Chelonia mydas*, in the Andaman Sea. The aims of this study are the understanding of the habitat use of this species and to propose the legitimate protected area for conservation of this species.

In chapter 1, reviews of the SEASTAR2000 were described. The SEASTAR2000 is a cooperative project between ASEAN countries and Japan was reported. Since 2000, Kyoto University started the ecological studies of sea turtles in Thailand because of the request of the Government of Thailand. Annual workshops were held by participants from more than 10 countries. Future plans of this project are highlighted; recording of vertical movement of sea turtles, a tracking of migration paths in the Andaman Sea and so on.

In chapter 2, the study site and target species were described. Field experiments of this study were conducted in Huyong Island, Thailand. While a nesting of sea turtles was generally known to occur in distinct season in each region, female green turtles nested throughout the year in Huyong Island. The result from a tagging study demonstrated that the variety of nesting season among individuals depend on environmental constraint but the fidelity of nesting season of each individual do not depend on them. This site was suitable and precious for this study and ecological studies.

In chapter 3, a remote tracking study of migration of green turtles was described. From 2001 to 2003, nine female green turtles were tracked using Argos system. This system records the movement of sea turtle using polar-obit NOAA satellite. The

tracking results showed that green turtles nested in Huyong Island had two migration patterns such that migrated to Andama Islands, India and to Phra Tong Island, Thailand. Once the tracking turtles arrived at their destination, they stayed there. Therefore, the destination may be feeding area of the turtles. Home ranges of the turtles were estimated from the location data of Argos system. Core areas of the home ranges during nesting period of the turtles existed in 6 km shore buffer areas of the nesting site. This moving pattern indicated saving a traveling cost. During feeding period, core areas of the turtles existed in 5 km shore buffer sea grass meadow might be distributed. It indicated the legitimate protected areas for conservation of this species.

Satellite tracking in chapter 3 provided the large-scale movement of sea turtles. However, we cannot understand the vertical movement and the fine-scale movement of them because the transmitter of Argos system sends the signal to satellite when at only the surface. Therefore, I developed a new technique to reconstruct three-dimensional moving path of a turtle. The magneto-resistive acceleration logger was used to record body directions and tilt angle of a turtle. And speed logger was used to record swimming speeds of a turtle. From these data, moving vectors was calculated at interval of 1 second. Estimated errors of vertical movement might affect to the paths because we could not attach the logger parallel with body axis completely. These errors were adjusted by comparison with the time series of depth profile. Horizontal movement also might affect to errors, especially, environmental factors.

Chapter 1: Introduction

1. 1. International conservation and management mechanism of straddling stocks including sea turtles

Straddling stocks occurring within the exclusive economic zones of two or more coastal States or both within the exclusive economic zone and in an area beyond and adjacent to it are remarked because knowledge of a management plan of these stocks is rudimentary. It is generally considered that the most important task of conservation and management of biological resources is a decision making on the management programs. In the case of straddling stocks, scientific researches are more essential because a consensus of the relational countries is needed to determine the management programs among the countries. However, the United Nation Convention of the Law of the Sea (UNCLOS) had not told clearly about the management of the straddling stocks. Recently, The "UN Implementing Agreement" of the straddling stocks and highly migratory species agreement within the UNCLOS (UNIA) adopted in 1995 have lead regional agencies to build up to their functions. Higashimura (2000) considered that expected functions of the regional agencies were:

1) Resource management: It means that a realization of the sustainable fishery.
2) Management leader: It is expected that regional agencies perform effectively as a center of international fishery agency.
3) Dispenser of wealth: The regional agency should work as the stage of dispenser of wealth.

A realization of sustainable use including a sustainable fishery is a goal of resource management. However there are a very few examples realized sustainable management because a real concern of the relational country is the decrease of uncertainty of their fishery rather than the number of populations. Although all relational countries assent the conservation and management, there are many oppositions among the courtiers (Higashimura, 2000). Therefore, to get a consensus of coastal countries and fishing countries, the management programs are usually decided based on the population dynamics. It is considered that the expected function of management leader is elimination of outsiders and holding of the exclusive franchise. But the effect of regional agency toward the nonmember has been unknown (Higashimura, 2000).

Recently, Community Based Conservation (CBC) is remarked as a new conservation and management program among the many countries. CBC is a strategy used throughout the world as a means to save wildlife (Hackel, 1998). There is no one definition of CBC but it is the commonly seen as having two objectives: to enhance conservation and to provide social and economic gains for local people (Campbell, 2003). The context to which projects are community-based is unknown because research on the extent of community support for conservation is lacking (Campbell, 2003). The goal of true CBC facilitators is to work local people themselves out of a job, so the test of success of CBC is whether conservation efforts continue in the absence of conservation organizations (Campbell, 2003). Campbell (2003) reported that claims of projects being community based need to be carefully considered, and research on the extent of support for conservation among communities is needed.

1. 2. Southeast Asia sea turtle associative research (SEASTAR2000)

In the ASEAN countries, economic developments are going remarkably. On the other hand, the extinctions of wildlife caused by the development are closed up in the world. Sea turtle species in the Southeast Asia that are the green turtle (*Chelonia mydas*), the loggerhead turtle (*Caretta caretta*), the hawksbill turtle (*Eretmochelys imbrecata*), the leatherback turtle (*Dermochelys coriacea*) and the olive ridley turtle (*Lepidochelys olivacea*) especially are remarked. Trawl shrimp fisheries are the basic industry in the ASEAN fishery. It is known that other species including sea turtle species are caught incidentally by fishing trawl net (It is generally called by-catch). United States imposed an economic sanction; it has been embargo on the import of shrimps caught by the fisheries that do not attach the Turtle Exclusive Device (TED), on the ASEAN countries in 1997. However, trawl fisheries in the ASEAN countries use small vessel, so they cannot manage their fishery using TED. A harmonic management programs between fishery and sea turtle species should be proposed, while knowledge of sea turtles in the ASEAN countries is rudimentary. Since 2000, ASEAN researchers and Japan researchers have conducted SEASTAR2000 project, the South East Asia Sea Turtle Associative Research 2000. The objectives of this project are:

1) Elucidation of the ecology of the sea turtles
2) Conservation of the sea turtles
3) A development of instruments for bio-logging science and sustainable conservation programs.

1. 3. Current results and discussion of SEASTAR2000

One of the major obstacles to study the sea turtle is the lack of adequate information on their migration paths and their habitats. Recently, the increased performance and miniaturization of satellite transmitter has been preceded the sea turtle tracking. Using satellite transmitters, it has been possible to ascertain the postnesting migration routes (Balazs et al. 1994; Hatase et al. 2002). In the SEASTAR2000, many results of satellite tracking of adult female turtles have been reported (Shiba et al., 2002; Monanunsapl et al., 2002; Kongkiat, 2002). Adult female green turtles were tracked using the satellite transmitters in the Gulf of Thailand in 2000 and 2001, and examined the relationship between the migration routes and shrimp fishing grounds (Shiba et al., 2002). The results show the habitats of female green turtles straddle the EEZ of Thailand, Cambodia, Vietnam, Malaysia and Indonesia. They reported that migration routes of female green turtles were divided into three groups and considered that there were differences between the migration routes and shrimp trawl fishing grounds vertically and horizontally in the Gulf of Thailand. It is important to elucidate the functions of the each EEZs as sea turtle habitats Naturally, to study on the life cycle of the turtles in cooperation with the relational countries is needed.

The migration tracking using satellite system provides the important information on the target species. To understand the further ecology of sea turtles and the relationship between various parameters, we have to study the vertical behavior of sea turtles and track the fine scale migration paths. Using data loggers, the vertical behavior and ecology of sea turtles has been elucidated (Hays et al., 2000; Hays et al., 2001; Hays et al., 2002; Sato et al., 1998). It is considered that future objective of this project is to elucidate the behavior of the turtles in the each EEZs using data loggers and the relationship between the behavior and the environments in the EEZs.

1. 4. Future plans of SEASTAR2000 and the objectives of this study

On the basis of Chapter 1, three future plans are highlighted:

1. Tracking and analysis of migration paths of green turtles in the Andaman Sea.
2. Study on the vertical movement of the green turtle.
3. Planning of the harmonic conservation and management between fishery and wildlife, especially sea turtles.

In the SEASTAR2000, Shiba et al (2002) analyzed the relationship between fishery and sea turtle species using satellite telemetry. However, migration paths of Andaman rookery are still unknown. And vertical movement of sea turtles did not be considered in past studies in the SEASTAR2000. Therefore, the objectives in this study are to track and analyze the migration paths of Andaman green turtle and to record the vertical movement of them using cutting edge technology. Finally, I will consider the plan of the harmonic conservation and management of green turtle in the Andaman Sea.

Chapter 2: Reproductive biology of green turtles nested in Huyong Island

2. 1. Introduction

Sea turtles have a strong fidelity to their reproductive areas and their feeding areas. Once a nesting female has returned to the region of its birth and selected the nesting beach, she will tend to reselect the same beach or other beach in relatively close proximity during subsequent nesting within that nesting season (Limpus et al. 1984; Bijorndal et al. 1985; Limpus et al. 1992; Miller 1997). Adult males and females migrate to their feeding areas after their courtships and/or laying eggs. In a feeding area, sea turtles accumulate energy for next reproduction. Therefore, it has been considered that reproductive interval depend on qualities and quantities of prey items in a feeding area (Bijorndal et al. 1980; Miller 1997). When males and females finish their preparation for reproduction in a feeding area, they travel to a reproductive area. Field observations of a courtship behavior suggest that the courtship generally occur in the vicinity of the nesting beach (Owens and Morris 1985; Limpus et al. 1993; Klom-in 2002; Hamann et al. 2003). Therefore, a reproductive cycle may be determined by some periods (e.g. energy accumulation, traveling from feeding area to reproductive area, courtship and egg growth and so on). However, for most nesting rookeries of green turtle (*Chelonia mydas*), which are distributed over the tropical and the temperate region worldwide, a nesting occurs in a distinct season, usually in the warmest months (Miller 1997; Godley et al. 2001). It was reported that peaks of the temporal distribution of the nesting activities were from August to October in Malaysia (De Silva 1969), from the middle of April to the beginning of June in Hawaii (Balazs 1980) and from the beginning of January to the beginning of May in Ascension Island (Godley et al. 2001) respectively. However, there are a few nesting beaches where green turtles nest through the year. Owens (1980) considered that the timing of reproduction in female sea turtles would be determined by factors that eggs are on the beach at an optimal time. For example, Godley et al. (2001) reported that the temporal distribution of nesting activities related with sand temperature. They reported that there were no nesting activities in low sand temperature season. They suggested that turtles might have evolved to nest during the time of appropriate sand temperature for hatch. Female sea turtles did not know whether their eggs were hatched, however, they selected an appropriate nesting season. This report is probably showed that green turtles had variations in their reproductive character (e.g. reproductive cycle and nesting season). Although knowledge of variations in reproductive characters of sea turtles is very important when the evolution and reproductive mechanism of sea turtles are studied, it is rudimentary.

To verify the possibility, nesting survey in the appropriate beach was demanded. In Huyong Island, Thailand, nesting female green turtles were observed through the year. In Huyong population, variations in a nesting season and/or nesting cycle of green turtles probably are needed to nest through the year. Therefore, nesting surveys are conducted in Huyong Island from 1996 to 2003. And a possibility that green turtles have variations on their nesting season and nesting cycle was examined.

2. 2. Materials and methods

Nesting survey was conducted in Huyong Island of Similan Islands in the Andaman Sea. The Huyong Island is a prominent nesting site of green turtles in Thailand. Length of the nesting beach in the Huyong Island is approximately 800 m. In this beach, nesting green turtles were observed through the year. Therefore, we patrolled the nesting beach through the year from 20:00 to 4:00 to find the nesting female green turtles. Female green turtles were internally tagged with PIT tags and externally tagged with inconel flipper tags to identify individuals. Curved carapace lengths (CCL) were also measured to the nearest 1 cm during their laying eggs. The PIT tags and the inconel tags were read after their laying eggs completely. If turtles failed to nest, neither measurement nor identifications were conducted so as not to disturb their next nesting.

The data collected from 1996 to 2003 were analyzed in this paper. In 2003 only, the data from January to June were analyzed. Green turtles nesting in the Huyong Island took a long term to lay eggs for one their nesting season (1-4 month) because turtles divided their laying eggs into several times (1-10 times) at intervals of approximately 14 days. To analyze their nesting season, we gave an eye to the nesting date when a turtle was identified firstly (N) in the nesting season. Some females remigrated to the beach at approximately 2 or 3 years later. We also focused on the returned date when the female remigrated and nested on the beach ($N + 1$) in the successive nesting season.

For Ascension Island, Hays et al. (1999) have been described the relationship between air temperatures and sand temperatures at nest depth (mean monthly sand temperatures (℃) = 1.6 + 0.908 mean monthly daily maximum temperature; $F_{(1, 10)}$ = 498, P < 0.001, r^2 = 0.98). In this paper, monthly sand temperature in Huyong island were estimated by mean daily maximum air temperature in Phuket Island (7°88N, 98°40E) for each year, 1996 to 2002, collected by the National Climatic Data Center (http://ncdc.noaa.gov/), using same equation.

2. 3. Results

The monthly number of nests of green turtles in the Huyong Island from January 1996 to June 2003 is shown in Fig. 2 and Table 2. During the nesting survey, 76 nesting turtles and 375 nests included 35 unidentified nests were found. The mean annual number of identified turtles was 10.1 (S.D.±6.3) turtles and the mean annual number of nest was 51.0 (S.D.±23.8) nests. Female green turtles nested several times at intervals of about 14 days during one nesting season. The mean nesting frequency in one nesting season was 4.8 (S.D.±0.5) times. Maximum nesting frequency was 10 times. The mean inter-nesting interval ranged from 12.9 (S.D.±3.2) to 17.1 (S.D.±11.1) days. Nesting female green turtles were observed through the year in the Huyong Island (Fig. 1). Although many females were tended to identify in April and June (Mean 1.3±1.0 turtles) and a few turtles were tended to identify in November (Mean 0.3±0.5 turtles), there were no significant difference of a number of identified turtles for each month (1-way ANOVA, d.f. = 11, $F = 0.739$, P = 0.696).

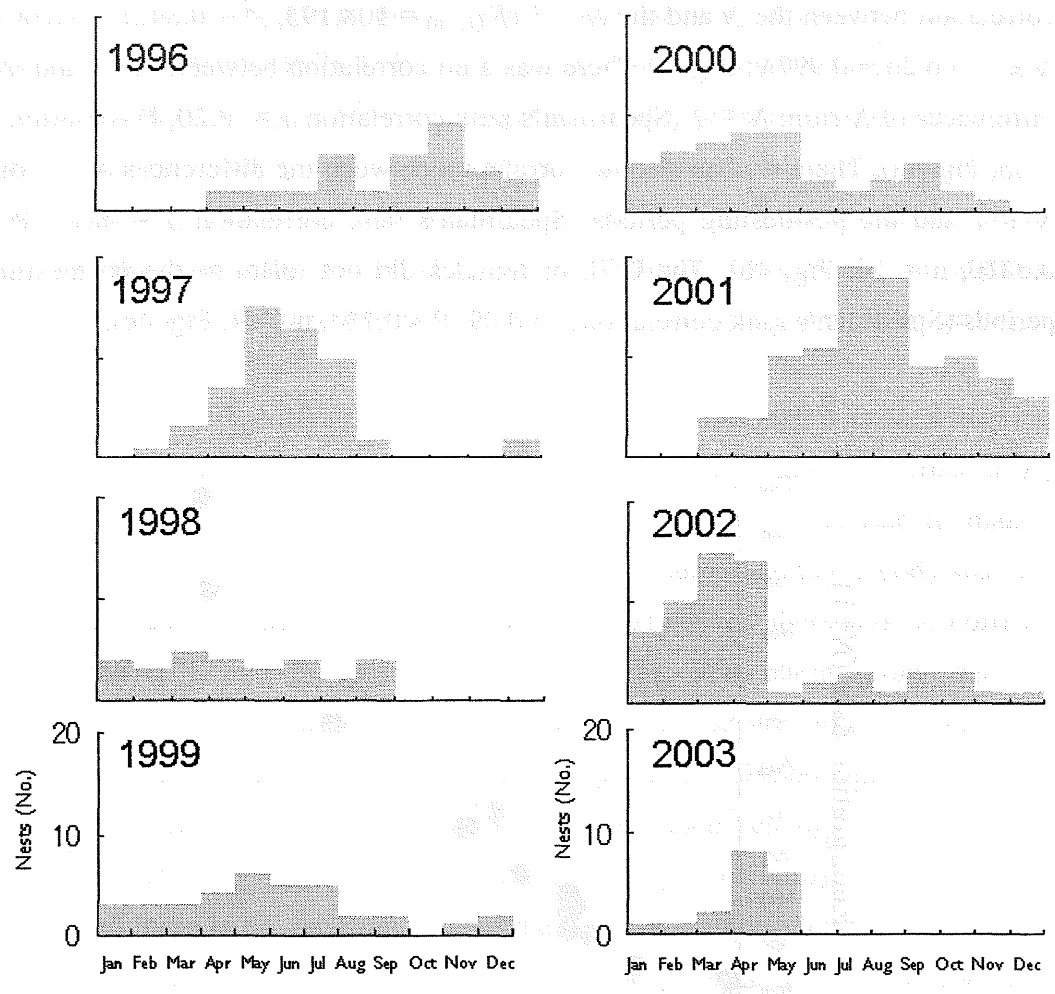


Fig.1. Monthly number of nests in Huyong Island, Thailand, from Jan 1996 to Jun 2003.

Fifteen identified females returned to the beach during our nesting survey. Table 3 shows the nesting date (*N*), the remigration date (*N* + *1*), the postnesting period and the difference between the *N* and the *N* + *1* of fifteen females, respectively. For example, Turtle 3 was identified in 22 April 1997 (*N* + *1*). This identified female nested 5 times in this nesting season from 22 April to 11 June. We subsequently found again this identified female in 23 April 2001 (*N* + *1*). Therefore, the difference between the nesting season and the next nesting season were understood + 1 day (23 April - 22 April). Only Turtle 2 returned 2 times in 2000 and 2002, respectively. The proportion of remigrated females to all identified turtle was 21.1 %. The Mean remigration interval was 1130.8 (S.D.±426.0) days. The Mean of differences of nesting seasons from next nesting seasons was 26.5 (S.D.±24.1) days.

Although the fifteen females remigrated at not same date, there was a strong correlation between the N and the $N + 1$ ($F_{(1, 16)} = 108.193$, $r^2 = 0.84$, P < 0.0001, $N + 1 = 6.26 + 0.997N$; Fig. 2) There was a no correlation between the N and the differences of N from $N + 1$ (Spearman's rank correlation ρ = -0.20, P = 0.4469, n = 16, Fig. 4a). There was an also no correlation between the differences of N from $N + 1$ and the postnesting periods (Spearman's rank correlation ρ = -0.13, P = 0.6210, n = 16, Fig, 4b). The CCL of females did not relate to the postnesting periods (Spearman's rank correlation ρ = 0.09, P < 0.734, n = 14, Fig. 4c).

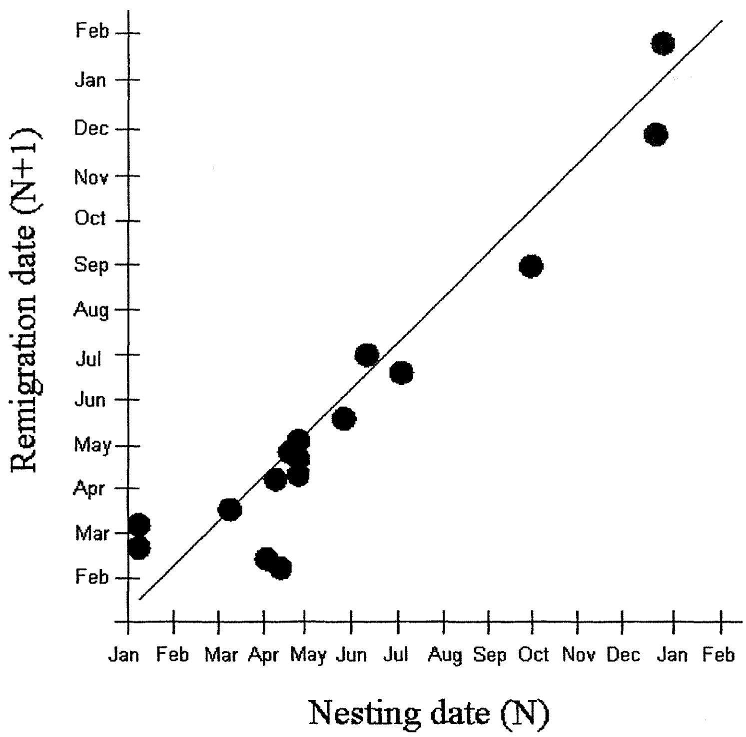


Fig.2. The relationship between nesting date (N) and remigration date (N+1) of fifteen female green turtles nested in Huyong Island, Thailand ($F_{(1, 16)} = 108.193$, $r^2 = 0.84$, P < 0.0001, $N + 1 = 6.26 + 0.997N$).

2. 4. Discussion

Preference of nesting season

There was a strong correlation between the nesting date (N) and the remigration date ($N + 1$) (Fig. 2). Adult female green turtles migrate between their feeding area and their reproductive area. The reproductive cycle of female green turtles may be linked on qualities and quantities of prey items (Bijorndal et al. 1980; Miller 1997) because females accumulate energy for oviposition in their feeding area (Miller 1997). Postnesting period of green turtles which was mainly herbivore were reported 2.86±0.23 year (Miller 1997). In Huyong Island where green turtles nested through the year, the reproductive cycle were also suggested that it differed among female turtles. Briefly, the postnesting period of some females that accumulate energy in an optimal season was seemed to be short. However, there was no significant correlation between the *N* and the postnesting period (Fig. 3a). In addition, there is also no significant correlation between the differences of *N* from *N + 1* and the postnesting period (Fig. 3b).

In this study, Turtle 2 and Turtle 3 nested in April 1997. Although it seemed they began a preparation for next nesting in the almost same condition, Turtle 2 returned in April 2000 and Turtle 3 returned in April 2001. As the reason that caused to make the difference between 2 females postnesting periods, we suggested that a body size linked on an energy accumulation for their reproduction. However, there was no correlation between the CCL and the postnesting period (Fig. 3c). These results show that available foods of green turtles have little seasonality in the Andaman Sea (Fig. 3a and Fig. 3c) and the postnesting period depend on an active season selection of female turtles (Fig. 2). Briefly, female green turtles preferred their nesting season respectively in Huyong Island (Fig. 2). It means that the nesting cycle of female green turtles is by the year and there is no variation in reproductive cycle among females. In addition it shows that female green turtles have a variation in their nesting season among individuals (Fig. 2). Although green turtles can nest through the year in Huyong Island, female turtles fixed their nesting season respectively. Therefore it is clearly shown that this character is a conservative character for green turtles.

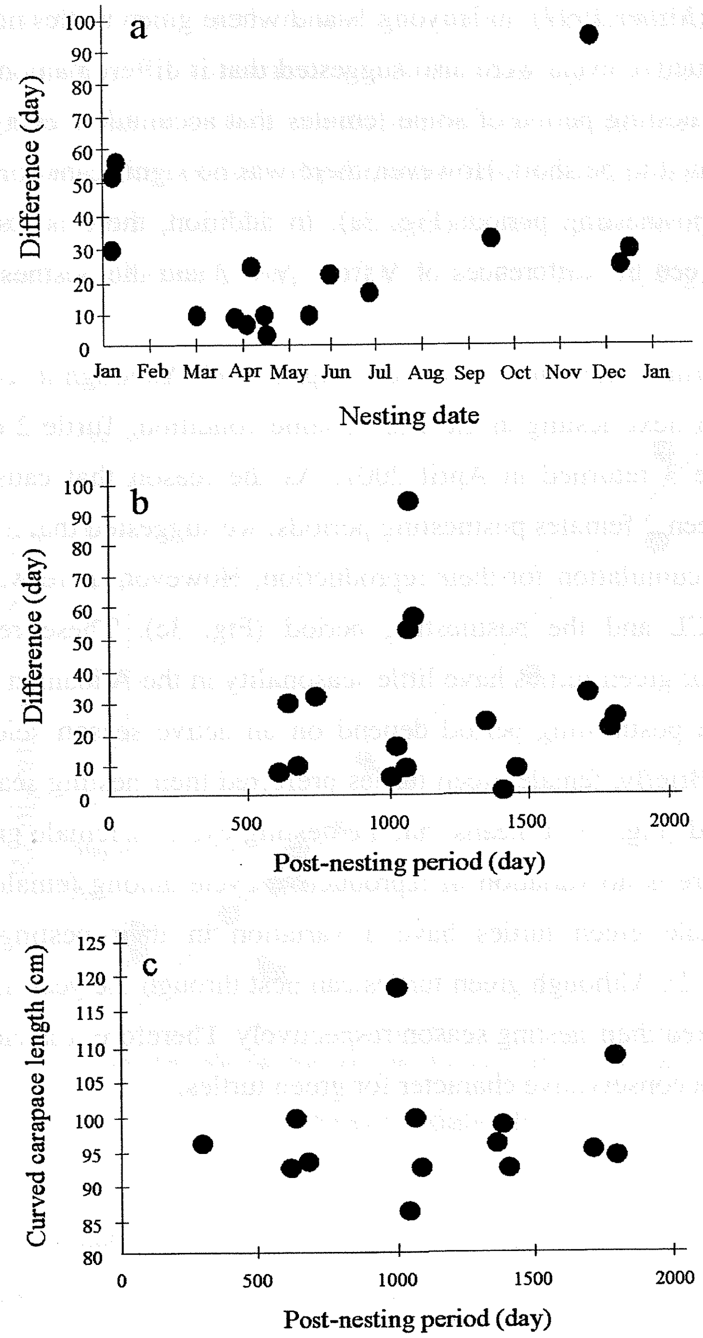


Fig.3. a: The relationship between nesting date and difference of N from N+1 (Spearman's rank correlation ρ = -0.20, P = 0.4469, n = 16). b: The relationship between post-nesting period and difference of N from N+1 (Spearman's rank correlation ρ = -0.13, P = 0.6210, n = 16). c: The relationship between post-nesting period and curved carapace length (Spearman's rank correlation ρ = 0.09, P < 0.734, n = 14)

Female green turtles selected their nesting season respectively in Huyong Island, but this character was rarely reported in other nesting beaches because the nesting of the green turtle has seasonality in the other beaches (Miller, 1997; Sato et al., 1997; Godley et al., 2001; Godley et al., 2002). Owens (1980) considered that the timing of reproduction in female sea turtles is determined by factors that eggs are on the beach at an optimal time. For example, Godley et al. (2001) reported that the temporal distribution of nesting activities related with sand temperature. They reported that there were no nesting activities in low sand temperature season. Therefore turtles may have evolved to nest during the time of appropriate sand temperature for hatch. In this study, our results have clearly support their consideration. We have shown female green turtles have a variation in their nesting season and do not have in their reproductive cycle among individuals. And we also showed that the reproductive cycle of green turtles is by the year. That is to say, the reason for the nesting seasonality of sea turtles is shown that females that selected an inappropriate season (e.g. low sand temperature season) were evolved. While, in Huyong Island, sand temperature condition was probably appropriate for an egg embryo every month (Fig. 5), so it is considered that the nesting is observed through the year now.

In this study, we considered what a season turtles select. Sixteen female green turtles remigrated on the beach for nesting at nearly same date, respectively (Fig. 2). This result shows the nesting season of individuals were determined and fixed by their first nesting season. We hypothesize two theories on the first nesting season when green turtles select. The one is females select their first nesting season randomly. Briefly, we considered females nest as soon as they have accumulated energy for a reproduction. Godley et al. (2002), however, reported that there were no nesting activities of green turtles in low sand temperature season in Ascension Island. Sea turtles do not confirm whether their nesting season is an optimal season for a sea turtle embryo or not. However, in many nesting beach, female green turtles nest on an optimal season for hatch. If female green turtles select their first nesting season randomly, seasonality of the nesting activities may have not been observed. The second hypothesis is females select a parental nesting season as their first nesting season. A nesting female sea turtle has remigrated to the region of its birth and selected the nesting beach (Miller 1997). Its parental nesting season is also likely to be inherited as well as the nesting site fidelity.

Local reproductive biology in Huyong Island

In Huyong Island, green turtles nest through the year. If fertile males exist every season or females can store sperm in vivo, females could nest every season. In this section, we have examined the local reproduction of Huyong rookery.

Freshwater turtle studies reported that the sperm storage tube was found in 12 species and the freshwater turtles had sperm storage ability (Gist and Congdon 1998; Sever and Hamlett 2002). However, in sea turtles, there were some confusion concerning courtship into the literature because some of early observations suggest that mating for fertilization of subsequent eggs occurred immediately following laying eggs and that females stored sperm for several years between reproductive periods (Owens et al 1980; Miller et al 1997). Some observations reported that courtship behavior of sea turtles occurred around a reproductive area (Owens and Morris 1985; Limpus 1993; Miller 1997). Although the courtship period appears to be well constrained temporally for the individual, appearance of females at the nesting beach is scattered over several months (Godley et al. 2001; Hamann et al. 2003). The average period from mating to nesting is 34.7 days (Wood and Wood 1980). Although sperm have been found adjacent to the vagina and the junction between the magnum and aglandular zone, specialized sperm storage areas have not been identified in sea turtles (Solomon and Baird 1979; Hamann et al 2003). It is thus generally accepted that mating occurs in the month or two just preceding the first ovipositional cycle of the season (Limpus et al. 1993; Miller et al. 1997). Therefore, we rejected the hypothesis that female green turtles selected a nesting season using sperm storage ability.

Generally female green turtles do not lay eggs every year (Hirth et al. 1980). However, male green turtles may breed every year (Limpus et al. 1993) or every two year (Miller 1997). It is unknown that reproductive cycles differ between males and females. Male sea turtles are promiscuous seasonal breeder and exhibit scramble mate-finding tactics (Limpus et al. 1993; Jessop et al. 1999; Hamann et al. 2003). Therefore, competition between males has been recorded in many courtship areas (Balazs 1980; Limpus et al 1993; Miller 1997). Jessop et al. (1999) and Jessop et al. (2000) proposed that reproductive fitness of a particular male was likely to be depended on its status. These reports probably are suggested that fertile males exist through the year in the reproductive area where fertile females also exist through the year.

Our results of satellite tracking showed female green turtles migrated and stayed to the coast of Andaman Islands or Phra Thong Island after their laying eggs (Fig. 4). Green turtles generally were herbivore. Sea glass meadows were expanded around the Phra Thong Island coast and Andaman Islands coast, so these area were feeding grounds of the females nested in Huyong Island. Similar to many other reports, courtship behaviors of this rookery were observed around Huyong Island (Klom-in 2002). Traveling costs for a reproduction of the Huyong rookery was seemed very low because distances between the reproductive area (Huyong Island) and the feeding areas are immediately 650 km (Andaman Islands) and 90 km (Phra Thong Island) respectively whereas the Ascension rookery migrated at least 2000 km (Hays et al. 2002). Briefly, it seems that the low cost helps the Huyong rookery, especially males, to migrate easily to the reproductive area as soon as they have prepared their reproduction. Such the geographical condition may enable the Huyong rookery to nest through the year (Fig. 1; Fig. 5).

In conclusion, we have clearly shown that female green turtles selected and fixed their nesting season. Our result has shown the reason for nesting seasonality of green turtles in many other nesting beaches. That is, females which select an inappropriate nesting season seem to be culled by the natural selection (e.g. environmental fluctuation) because sea turtles become inactive, subsequently dead, as ambient temperature is lowed (Spotila et al. 1997) and there is the limit of the thermal tolerance range for sea turtle embryos are 25 – 27℃and 33 – 35℃(Ackerman 1997). In Huyong Island, all populations seem to be survived because estimated monthly sand temperature was prepared for embryo through the year (Fig. 5). In addition, the geographical condition of the Andaman Sea probably helps the populations to survive.

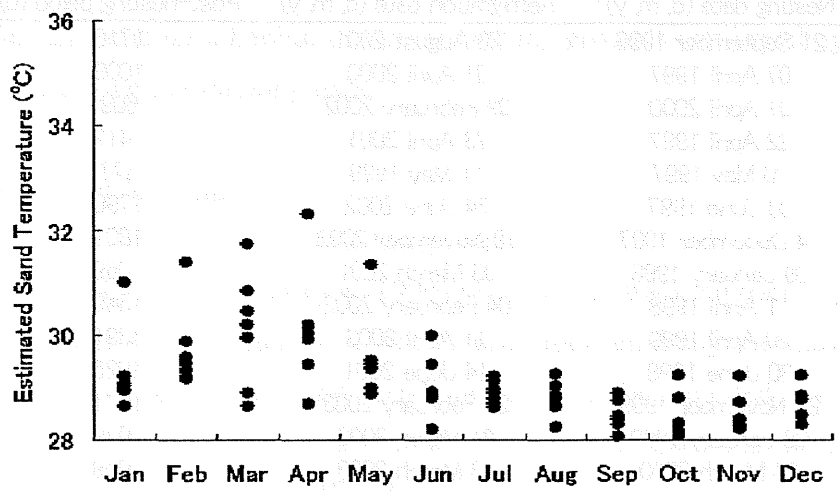


Fig.5. Monthly mean sand temperature from 1996 to 2003 predicted using relationship between monthly mean maximum air temperature and sand temperature at depth (Hays et al. 1999).

Table 1. The ID of Transmitter, a Kind of transmitter, Attachment date and Carapace length of each turtle.

ID	Transmitter	Attached Date	CCL (cm)
19278	Telonics ST-18	10 June 2000	119
18683	KiwiSat 101	5 September 2000	110
13062	KiwiSat 101	10 June 2001	93
9784	KiwiSat 101	2 September 2001	101
9780	KiwiSat 101	3 September 2001	88
9730	KiwiSat 101	17 September 2001	96

Table 2. Summary of the result of the nesting survey in Huyong Island from January 1996 to June 2003.

Year	Identified turtles (No.)	Nests (Unidentified) (No.)	Nesting frequencies (No.) mean	max	min	Mean internesting interval (d)
1996	2	36 (27)	4.5	7	2	13.3
1997	10	53 (3)	5.6	8	3	12.6
1998	4	29 (3)	5.0	6	4	17
1999	13	36 (0)	3.9	10	1	25.5
2000	9	43 (1)	4.7	10	1	17.1
2001	21	99 (1)	5.1	8	1	14.0
2002	12	61 (1)	4.8	8	1	14.8
2003	5	18				13.2
All	76	375 (36)	4.2	10	1	15.9

Table 3. Turtles number, Nesting date, Remigration date, Post-nesting season and Difference between nesting date and remigration date of each turtle.

Turtle no.	Nesting date (d, m, y)	Remigration date (d, m, y)	Post-nesting peiod (d)	Difference (d)
1	21 September 1996	23 August 2001	1716	+ 33
2	07 April 1997	01 April 2000	1009	− 6
	01 April 2000	09 February 2002	609	+ 8
3	22 April 1997	23 April 2001	1412	+ 1
4	20 May 1997	11 May 1999	677	− 9
5	03 June 1997	24 June 2002	1790	+ 21
6	14 December 1997	19 November 2002	1801	+ 25
7	09 January 1998	03 March 2001	1069	+ 53
8	11 April 1998	04 February 2002	1349	− 24
9	20 April 1999	11 April 2003	1391	− 9
10	30 June 1998	14 June 2001	1025	− 16
11	25 November 1999	27 February 2003	1071	+ 94
12	08 January 1999	01 March 2002	1079	+ 56
13	04 March 2000	13 March 2003	1059	+ 9
14	06 January 2000	18 February 2002	639	+ 29
15	15 December 2001	15 January 2003	307	+ 31

Chapter 3: Migration paths and home ranges of green turtles in the Andaman Sea

3. 1. Introduction

Adult sea turtles are among the largest living reptiles and the only reptiles that perform long-distance migration that rival those of terrestrial and avian vertebrate. Sea turtles are known to perform long-distance oceanic migrations between disparate feeding areas and breeding areas. The results of tagging and telemetry studies demonstrate adult sea turtles travel hundreds to thousands of kilometers between feeding areas and breeding sites at regular or seasonal intervals. For instance, green turtles nested in Ascension Island migrated more than 2000 kilometers to the coast of Brazil.

In SEASTAR2000, some studies tracked the migration paths of sea turtles (green turtle, loggerhead turtle and hawksbill turtle) to know their feeding areas and analyze relationships between some parameters of fishery and their habitat (Shiba et al., 2002; Monanunsapl et al., 2002; Kongkiat, 2002). However, the migration paths of sea turtles distributed in the Andaman Sea are still unknown.

Home range is utilized for conservation of wild life, while their habitat use remains poorly understand. Defining a home range requires the repeated sighting of individuals over extended time intervals. Because sea turtles spend 99 % of their lives underwater, home range studies require remote telemetry or in-water capture programs that are both labor-intensive and extensive. In this chapter, I report the tracking results of the migration paths of female green turtles nested in Huyong Island, Thailand in the Andaman Sea and analyze a habitat use in the feeding grounds and breeding area using the GIS tool form satellite tracking data.

3. 2. Materials and Methods

Tracking system

Argos satellite tracking system (Argos, 1996) was used to track migration paths of the female green turtle. Argos system is a widely used tool, enabling the movement of a large variety of terrestrial, aquatic and aerial vertebrates to be recorded (e.g. Hays et al., 2002; Hatase et al., 2002; Shiba et al., 2002). This system uses transmitters (termed platform terminal transmitter of PTT) that periodically send a short radio signal to polar-orbit NOAA satellites (typically at an interval of around 60s, 360-920 ms, 401.650 MHz). The location of the transmitter is calculated from the Doppler shift in the frequency of the transmissions received by a satellite as it approaches and then moves away from the transmitter on a signal overpass. The locations provided by the Argos system are classified according to six grades (termed location class or LC) of varying accuracy as LC 3, 2, 1, 0, A or B. This LC 3, 2, 1 and 0 may be provided only when at least four uplinks (means a PTT send a signal to the satellite) are received on an overpass. Argos (1996) gave that the estimated accuracy in latitude and longitude is < 150 m for LC 3, between 150 and 350 for LC 2, between 350 and 1000 for LC 1 and > 1000 m for LC 0. Argos is unable to assign a level of accuracy to LC A and LC B.

Turtles and Analysis methods

Seven female green turtles nested in Huyong Island were tracked using Argos satellite tracking system during inter-nesting period and post nesting period. Transmitters (Kiwi SAT 101 and Telonics ST-16; see Shiba et al., 2001) were attached on the carapaces of the females by epoxy adhesive after laying eggs completely. Table 4 shows that ID of transmitter, Curved carapace length of females, Attachment time, and a kind of transmitter of 5 female green turtles that tracked during post-nesting period. Migration speeds were calculated form a straight distance between the locations. If migration speeds exceed with 5 km/h (Lusch et al., 1998), we delete the location.

The locations provided by Argos were analyzed using Arc View version 3.1 geographic information system (GIS) software (Environmental Research Systems Institute; www.esri.com/software/arcview). Home range areas were estimated with the minimum convex polygon (Burt, 1943) and the fixed kernel density (Worton, 1989) methods using the animal movement analysis extension (US Geological Survey, Anchorage, Alaska; www.absc.usgs.gov/glba/gistool/#animal) for the Arc View. Minimum convex polygon areas were based on the 100 % outer edges. Fixed kernel home ranges were estimated with least square cross validation as a band-width (termed a smoothing parameter). A 95 % utilization distribution was used to estimate the over all home range used by a turtle, whereas a 50 % utilization distribution was used to establish the core area of activity. To estimate the home range areas of female green turtles during feeding period, we have to educe the locations during feeding period from all sample data. When the tracking turtles arrived the Andaman Island, the migration speeds of the tracking turtles were become low. And there are prey item of green turtles (e.g. algae) in a shallow area (< 10 m).

Table 4. Summary of tracking turtle during post nesting period

ID	CCL (cm)	Tagged Date	Transmitter
19278	100	2000/6/10	Kiwisat101
9730	84	2001/9/17	Kiwisat102
9784	90.4	2001/9/2	Kiwisat103
9780	96	2001/9/3	Kiwisat104
13062	n.d.	2001/6/10	Kiwisat105

3. 3. Results and discussion

Migration paths during Post-nesting period

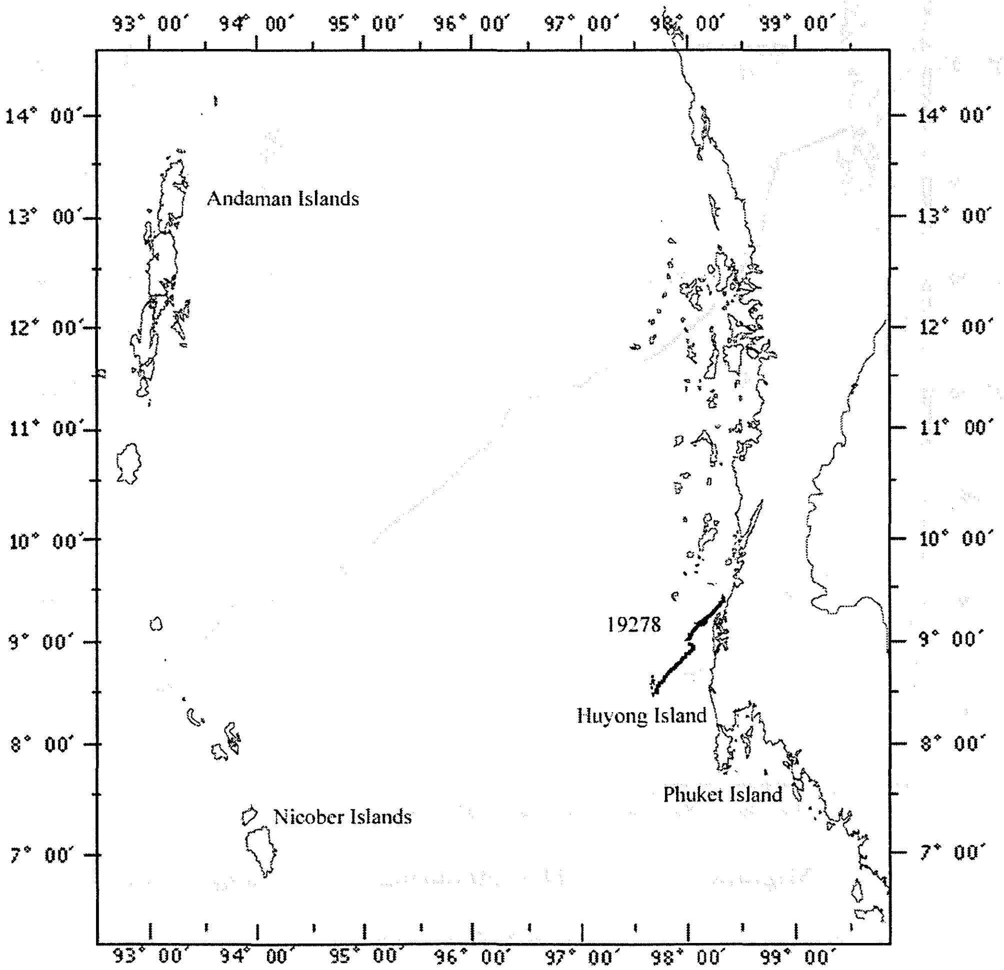


Fig. 6. Migration Path of ID 19278 during post-nesting period

ID 19278

ID19278 nested in 11 June 2001 and was attached the transmitter (Kiwi SAT 101) on her carapace. Tracking duration of this turtle was from 9 June to 7 July (approximately 28 days). After their laying eggs, ID19278 traveled toward Phra Tong Island where located northeastward 90 km from Huyong Island during inter-nesting period and returned to the nesting beach approximately 14 days. She re-traveled to Phra Tong Island and stayed there after inter-nesting period. Total migration distance was 500.5 km. Migration speeds ranged from 0.05 km/h to 4.49 km/h (mean 0.94 ± 1.12). The locations provided by Argos system were 15 % of LC 1, 3 % of LC 0, 13 % of LC A and 74 % of LC B (n = 30).

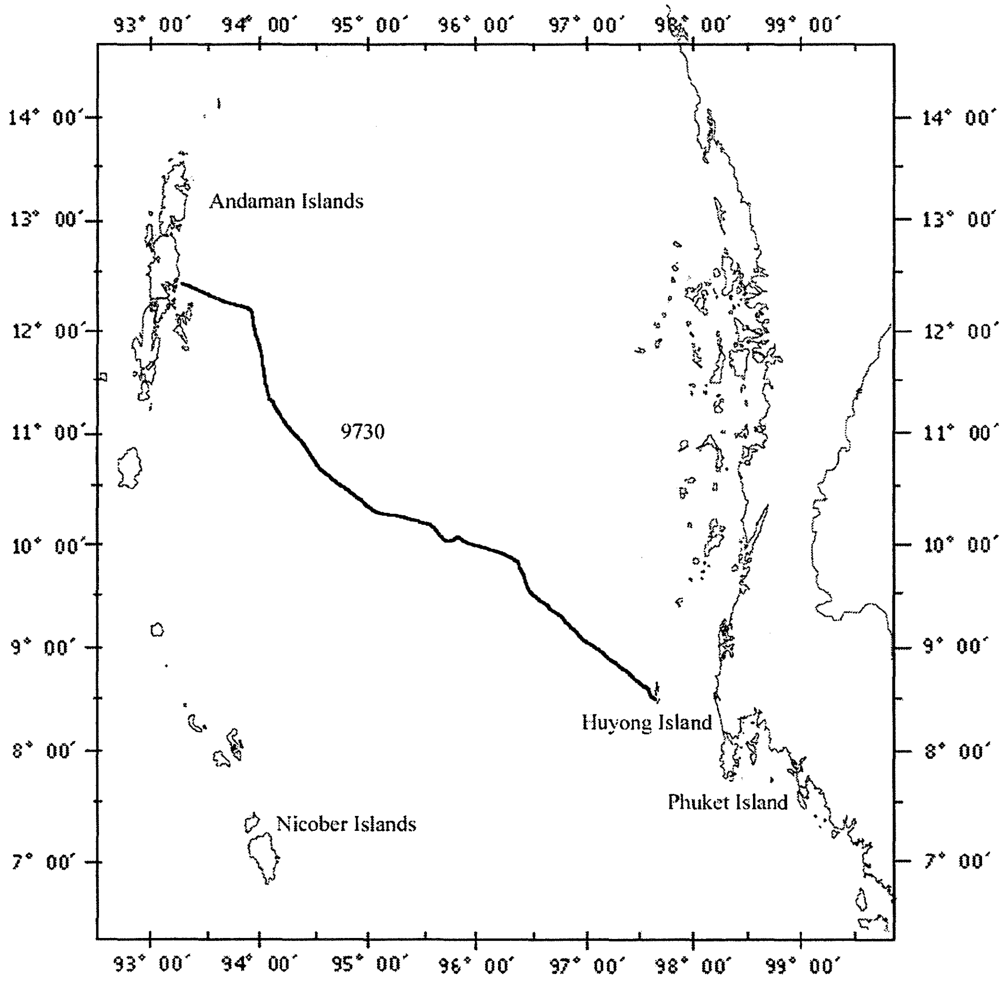


Fig. 7. Migration Path of ID 9730 during post-nesting period

ID 9730

ID 9730 nested in 17 September 2001 and was attached the transmitter (Kiwi SAT 101) on her carapace. Tracking duration of this turtle was from 18 September 2001 to 23

January 2002 (approximately 127 days). During inter-nesting period, this female stayed around Huyong Island. After their laying eggs, ID 9730 traveled toward Andaman Islands, India where located northeastward about 650 km from Huyong Island during post-nesting period. Total migration distance was 2866.2 km. Migration speeds ranged from 0.03 km/h to 4.96 km/h (mean 1.49 ± 1.39). The locations provided by Argos system were 2 % of LC 3, 9 % of LC 2, 8 % of LC 1, 20 % of LC 0, 17 % of LC A and 44 % of LC B (n = 205).

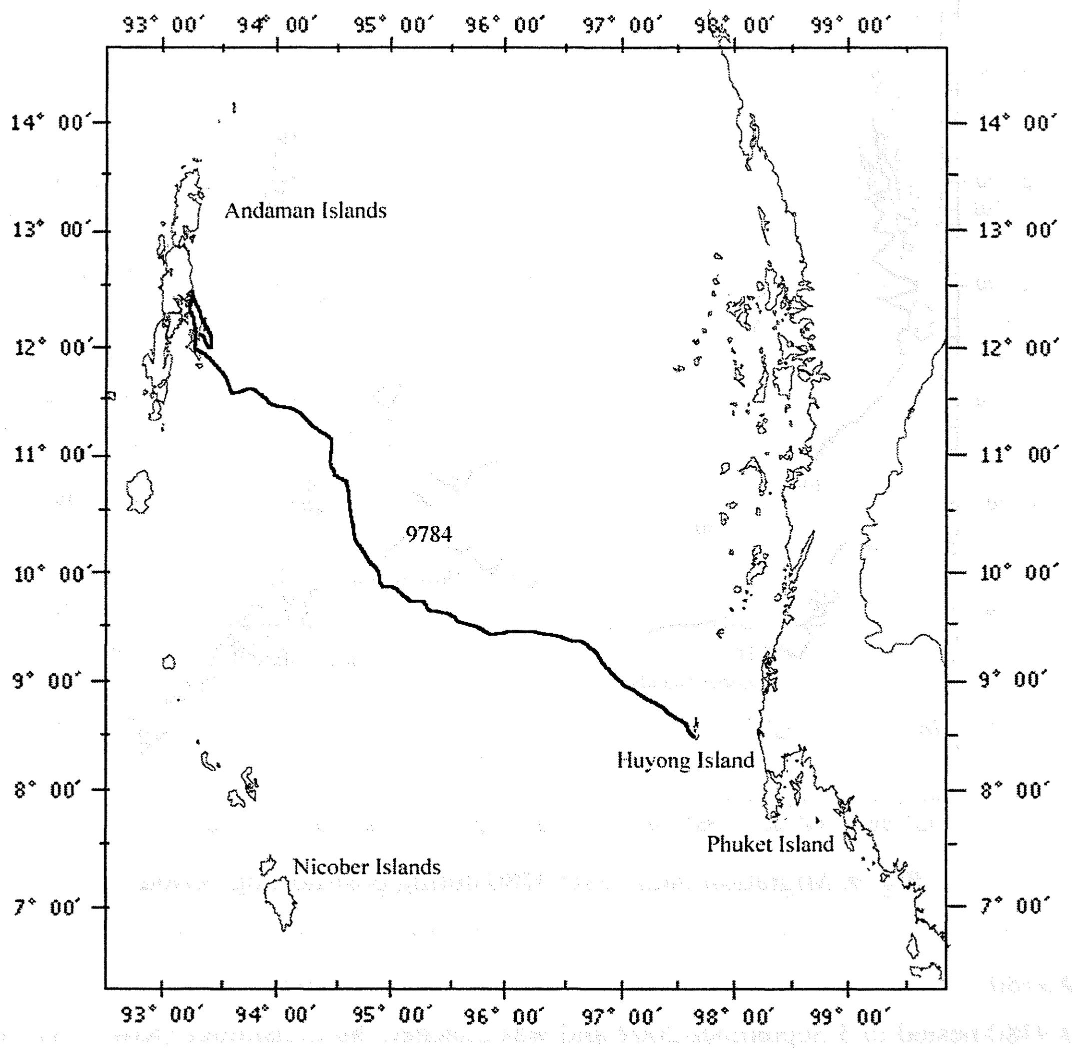


Fig. 8. Migration Path of ID 9784 during post-nesting period

ID 9784

ID 9784 nested in 2 September 2001 and was attached the transmitter (Kiwi SAT 101) on her carapace. Tracking duration of this turtle was from 3 September 2001 to 14 October 2002 (approximately 41 days). After the attachment, ID 9784 traveled toward Andaman Islands, India where located northeastward about 650 km from Huyong

Island. Total migration distance was 1720.1 km. Migration speeds ranged from 0.12 km/h to 4.96 km/h (mean 2.15 ± 1.27). The locations provided by Argos system were 7 % of LC 3, 4 % of LC 2, 14 % of LC 1, 9 % of LC 0, 24 % of LC A and 42 % of LC B (n = 134).

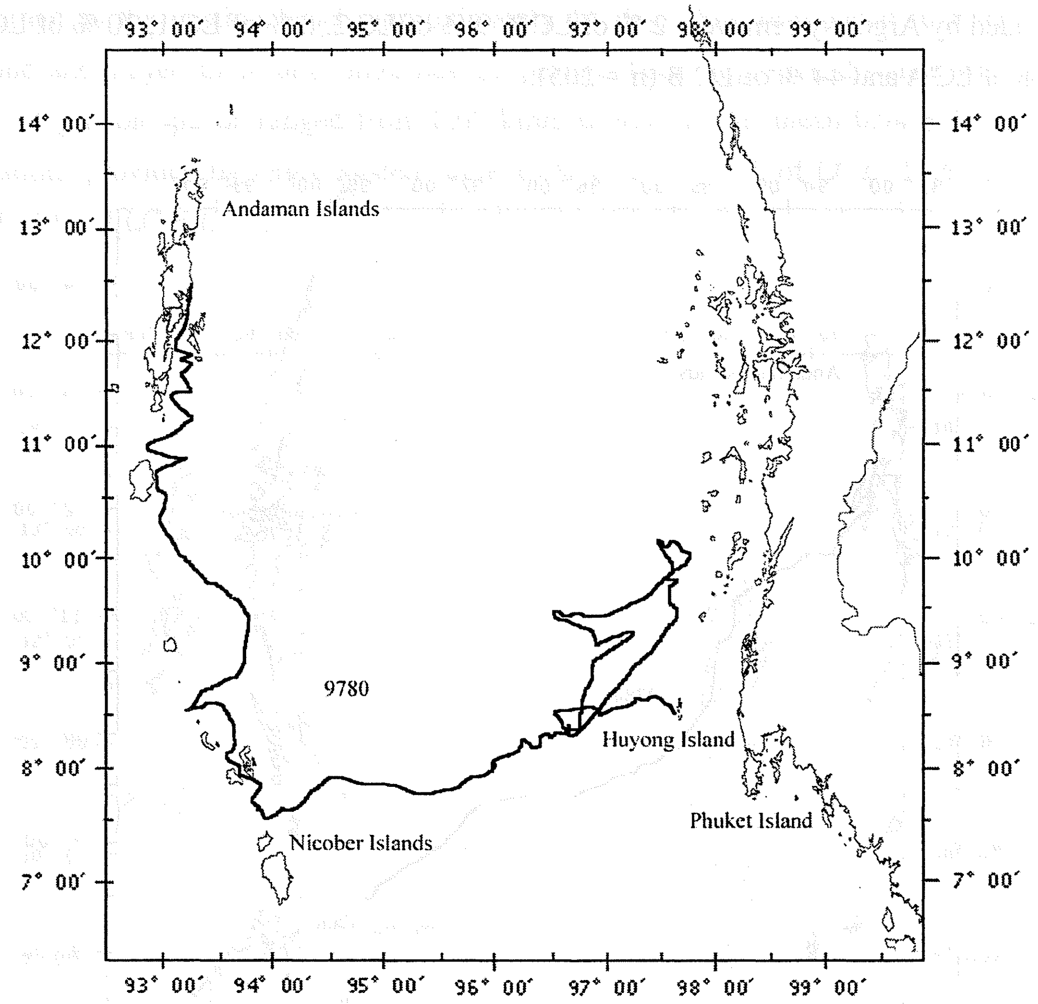


Fig. 9. Migration Path of ID 9780 during post-nesting period

ID 9780

ID 9780 nested in 3 September 2001 and was attached the transmitter (Kiwi SAT 101) on her carapace. Tracking duration of this turtle was from 4 September 2001 to 23 November 2001 (approximately 79 days). After their laying eggs, ID 9780 traveled toward Andaman Islands, India where located northeastward about 650 km from Huyong Island during post-nesting period. Total migration distance was 1919.1 km. Migration speeds ranged from 0.01 km/h to 4.93 km/h (mean 2.09 ± 1.22). The locations provided by Argos system were 4 % of LC 3, 9 % of LC 2, 13 % of LC 1, 6 % of LC 0, 25 % of LC A and 43 % of LC B (n = 399).

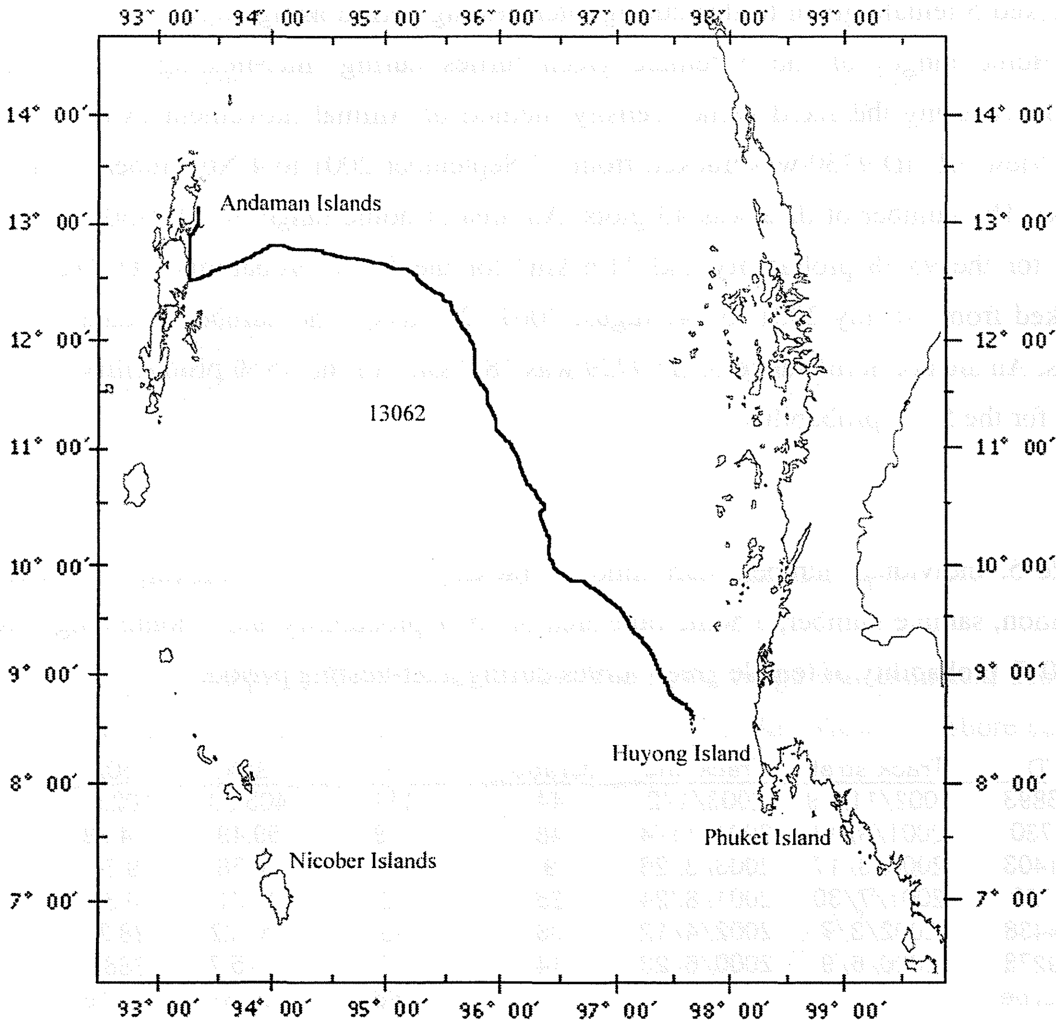


Fig. 10. Migration Path of ID 13062 during post-nesting period

ID 13062

ID 13062 nested in 17 September 2001 and was attached the transmitter (Kiwi SAT 101) on her carapace. Tracking duration of this turtle was from 18 September 2001 to 23 January 2002 (approximately 127 days). During inter-nesting period, this female stayed around Huyong Island. After their laying eggs, ID 9730 traveled toward Andaman Islands, India where located northeastward about 650 km from Huyong Island during post-nesting period. Total migration distance was 2866.2 km. Migration speeds ranged from 0.03 km/h to 4.87 km/h (mean 1.18 ± 1.27). The locations provided by Argos system were 1 % of LC 3, 3 % of LC 2, 7 % of LC 1, 2 % of LC 0, 19 % of LC A and 68 % of LC B (n = 173).

A home range during Inter-nesting period

I tracked 5 female green turtles during inter-nesting period using Argos system (Table 5). Home ranges of the 5 female green turtles during inter-nesting period were estimated using the fixed kernel density method of Animal movement extension for Arc View 3.1. ID 9730 was tracked from 17 September 2001 to 4 November 2001 (48 days). The number of data was 43 plots. An area of home range of ID 9730 was 56.2 km^2 for the 95 % probability and 11.6 km^2 for the 50 % probability. ID 9729 was tracked from 30 July 2001 to 24 August 2001 (25 days). The number of data was 33 plots. An area of home range of ID 9729 was 18.0 km^2 for the 95 % probability and 5.1 km^2 for the 50 % probability.

Table 5. Individual number, start time of tracking, end time of tracking, a tracking duration, sample number, a home rage area of 95 % probability and a home range area of 50 % probability of female green turtles during inter-nesting period.

ID	Track strat	Track end	Duration	n	95%	50%
36893	2002/11/19	2003/1/2	44	111	405.58	102.96
9730	2001/9/17	2001/11/4	48	118	69.49	14.29
31403	2003/3/17	2003/3/26	9	43	16.58	9.24
9729	2001/7/30	2001/8/24	25	33	22.31	6.32
24438	2002/3/7	2002/4/12	36	85	157.22	28.29
19278	2000/6/9	2000/6/23	14	17	2715.7	388.1
5turtle				386	107.67	21.16

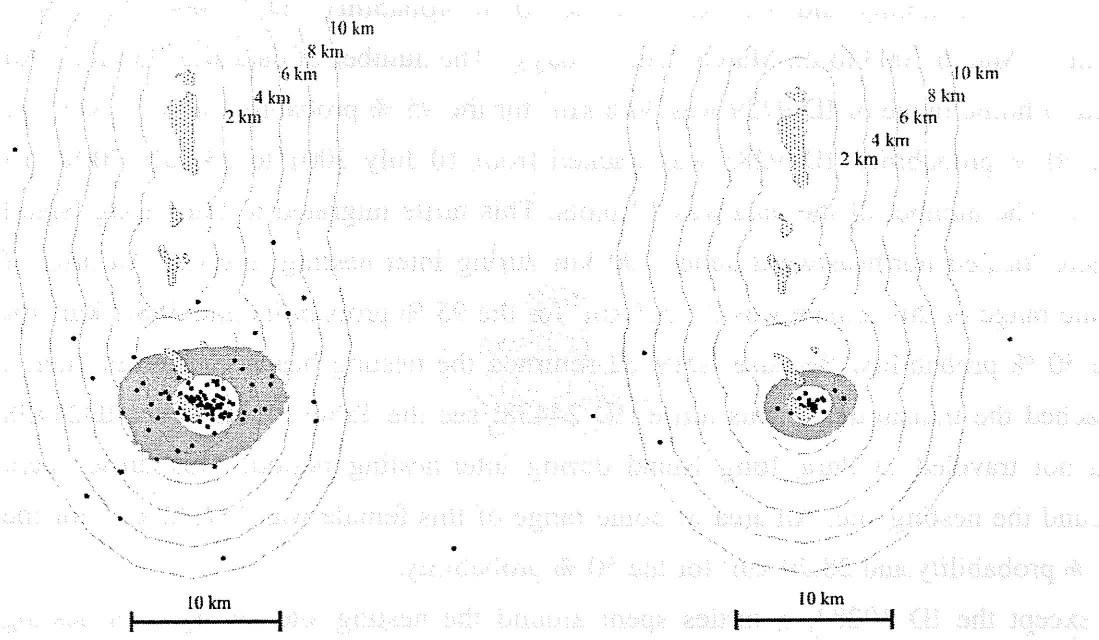


Fig. 11. A home range of ID 9730 and 9729. The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1. Shore buffer lines were written at interval of 2 km from the Islands.

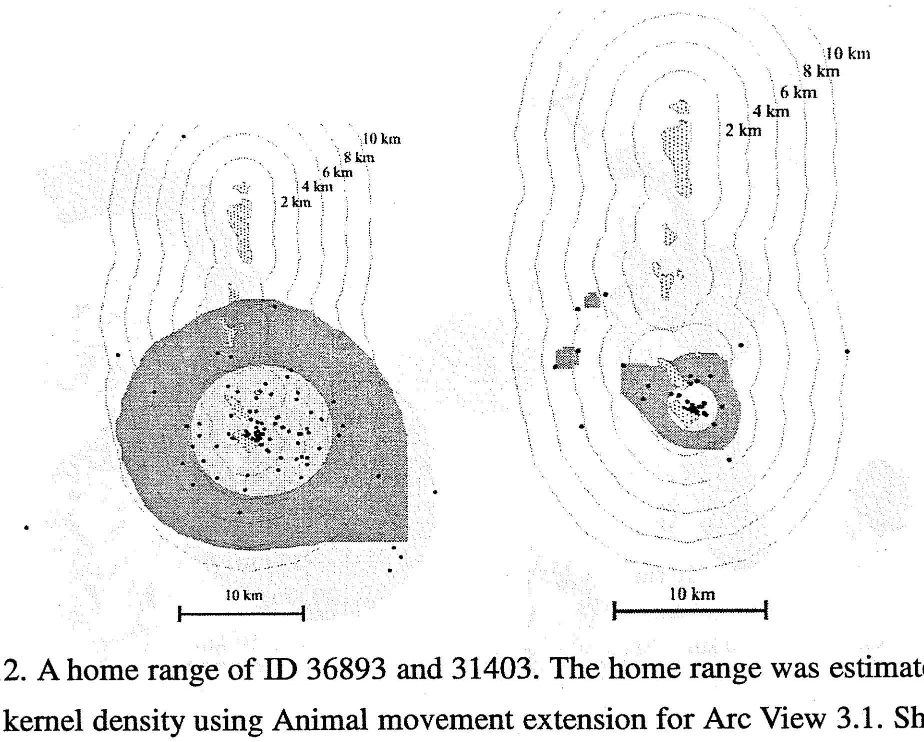


Fig. 12. A home range of ID 36893 and 31403. The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1. Shore buffer lines were written at interval of 2 km from the Islands.

ID 36893 was tracked from 19 November 2002 to 2 January 2002 (44 days). The number of data was 111 plots. An area of home range of ID 36893 was 328.1 km^2 for the 95 % probability and 83.2 km^2 for the 50 % probability. ID 31403 was tracked from 17 March 2003 to 26 March 2003 (9 days). The number of data was 33 plots. An area of home range of ID 9729 was 34.6 km^2 for the 95 % probability and 7.6 km^2 for the 50 % probability. ID19283 was tracked from 10 July 2001 to 23 July 2001 (13 days). The number of the data was 17 plots. This turtle migrated to Phra Tong Island where located northeastward about 100 km during inter-nesting interval. An area of home range of this female was 2715.7 km^2 for the 95 % probability and 388.1 km^2 for the 50 % probability. Because ID19782 returned the nesting beach at 2 years later, I attached the transmitter to this turtle (ID 24438; see the Table 5). However ID24438 did not traveled to Phra Tong Island during inter-nesting period. This turtle spent around the nesting site. An area of home range of this female was 157.22 km^2 for the 95 % probability and 28.29 km^2 for the 50 % probability.

Except the ID 19283, 5 turtles spent around the nesting site during inter-nesting period. Therefore, a homes range was estimated by the 4 turtles data. An area was 107.67 km^2 for the 95 % probability and 21.16 km^2 for the 50 % probability.

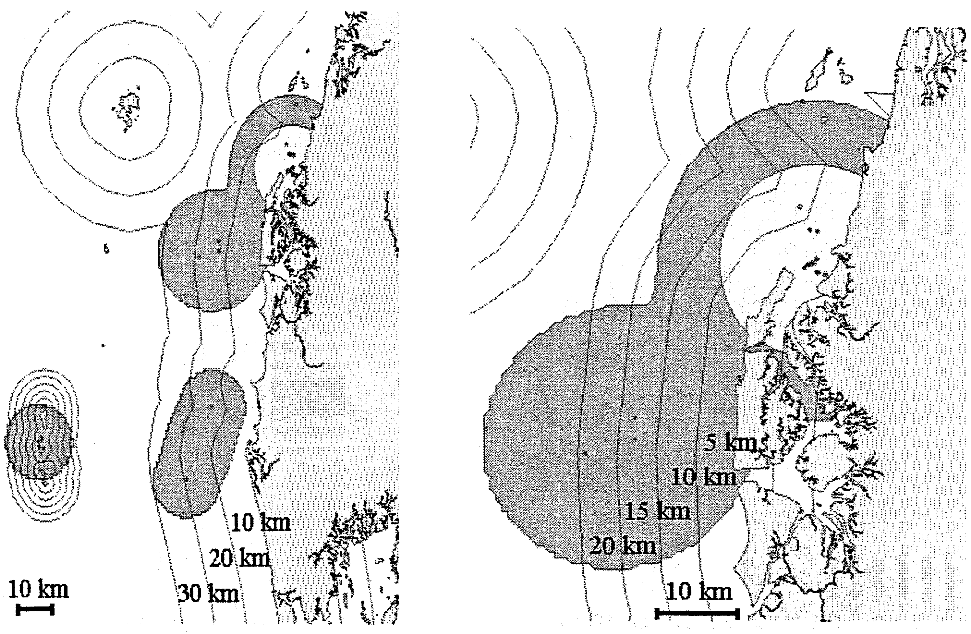


Fig. 13. A home range of ID 19278 (left) and an expanded home range of ID 19283 (right). The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1.

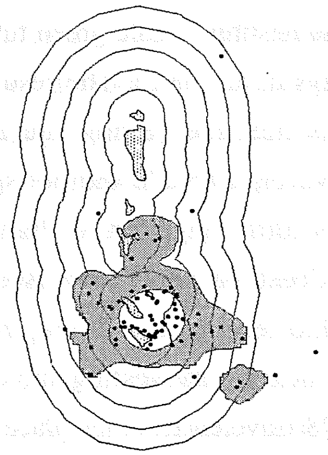


Fig. 14. A home range of ID 24438. The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1.

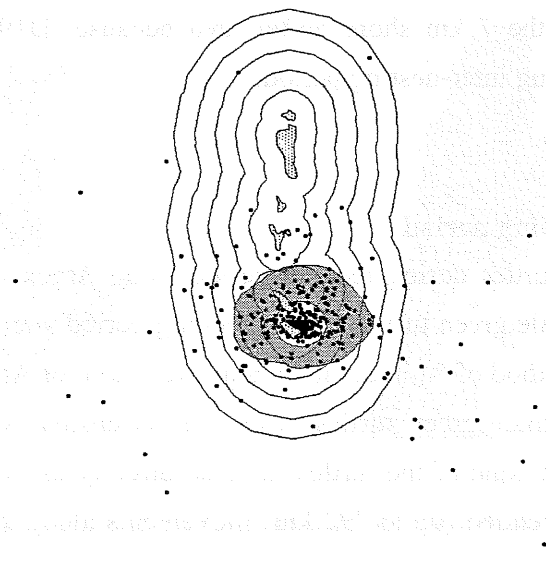


Fig. 15. A home range of 5 turtles. The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1. Shore buffer lines were written at interval of 2 km from the Islands.

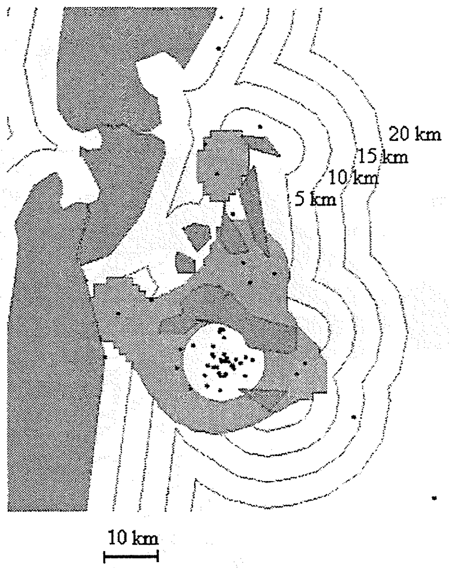
During inter-nesting period, female green turtles are known that they do not feed because there were few prey items around the nesting site (Hays et al., 2002). Therefore, optimal strategy of the nesting female green turtle was known to rest at the seabed near the nesting site (Hays et al, 2002). The results of this chapter show that nesting female green turtles stay near the nesting site and did not travel far away during inter-nesting period. However, ID19278 did not spend around the nesting site during inter-nesting period. This turtle migrated to Phra Tong Island where located northeastward about 100 km. Coast of Phra Tong Island, sea glass meadow was expanded. ID19278 might travel to feeding area during inter-nesting period because a coast of Phra Tong Island exists near by the nesting site compared with the Andaman Island (Fig. 6). Because ID19278 traveled to other place, the home range area of ID 19278 was large. ID19782 returned the nesting beach at 2 years later, and I attached the transmitter to this turtle (ID 24438; see the Table 5). However ID24438 did not traveled to Phra Tong Island during inter-nesting period. It may mean that female turtles have some moving pattern. Shortly, This turtle probably selected their migration pattern by environmental factor (e.g. ocean current).

For other 5 turtles, core areas of each female turtle contained 6 km shore buffer area, and a home range area that was estimated by 5 turtles data contained 7 km shore buffer area (Fig. 14). This result shows that a legitimate marine protect area for the nesting sea turtle conservation is the 7 km shore buffer area because ID19278 did not use around the nesting site during inter-nesting period.

A home range during feeding period

I tracked 6 female green turtles during feeding period using Argos system (Table 6). Home ranges of the 6 female green turtles during feeding period were estimated using the fixed kernel density method of Animal movement extension for Arc View 3.1. Hays et al. (2002) tracked 5 female green turtles nested in Ascension Island during post nesting. They reported that none of the turtles traveled directly to its final destination but, instead, there were extended (up to 792 km) movements along the coast after the oceanic crossing. Also in this study, some female green turtles did not traveled directly to its final destination and they moved to its final destination after arrival on Andaman Islands (see the results of migration tracking). Therefore, I defined the start of feeding period as the arrival date in the coast of Andaman Islands.

Feeding period of ID9730 was 15 November 2001 to 23 January 2002 (69 days). The number of data was 57 plots. An area of home range of ID 9730 was 1042.4 km^2 for the 95 % probability and 181.6 km^2 for the 50 % probability. Feeding period of ID13062 was 26 June 2001 to 16 October 2001 (112 days). The number of data was 176 plots. An area of home range of ID 13062 was 337.6 km^2 for the 95 % probability and 29.3 km^2 for the 50 % probability. Feeding period of ID9780 was 25 October 2001 to 23 November 2001 (29 days). The number of data was 58 plots. An area of home range of ID 9730 was 97.7 km^2 for the 95 % probability and 19.7 km^2 for the 50 % probability. Feeding period of ID9784 was 17 September 2001 to 14 October 2001 (27 days). The number of data was 39 plots. An area of home range of ID 9730 was 270 km^2 for the 95 % probability and 73.7 km^2 for the 50 % probability. Feeding period of ID18683 was 24 September 2001 to 5 October 2001 (11 days). The number of data was 8 plots. An area of home range of ID 18683 was 80.1 km^2 for the 95 % probability and 20.2 km^2 for the 50 % probability. Feeding period of ID24438 was 24 September 2001 to 5 October 2001 (11 days). The number of data was 8 plots. An area of home range of ID 24438 was 152.9 km^2 for the 95 % probability and 22.6 km^2 for the 50 % probability.



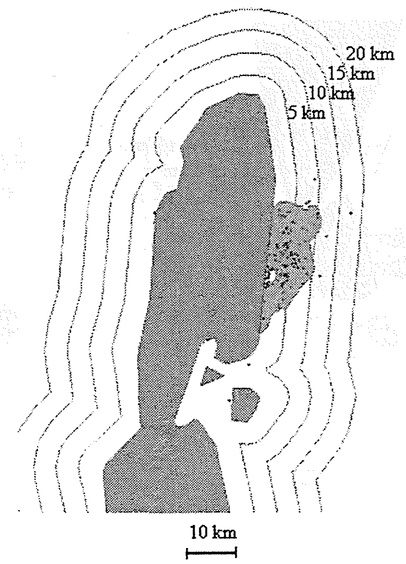


Fig. 16. A home range of ID 9730 (left) and an expanded home range of ID 13062 (right). The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1.

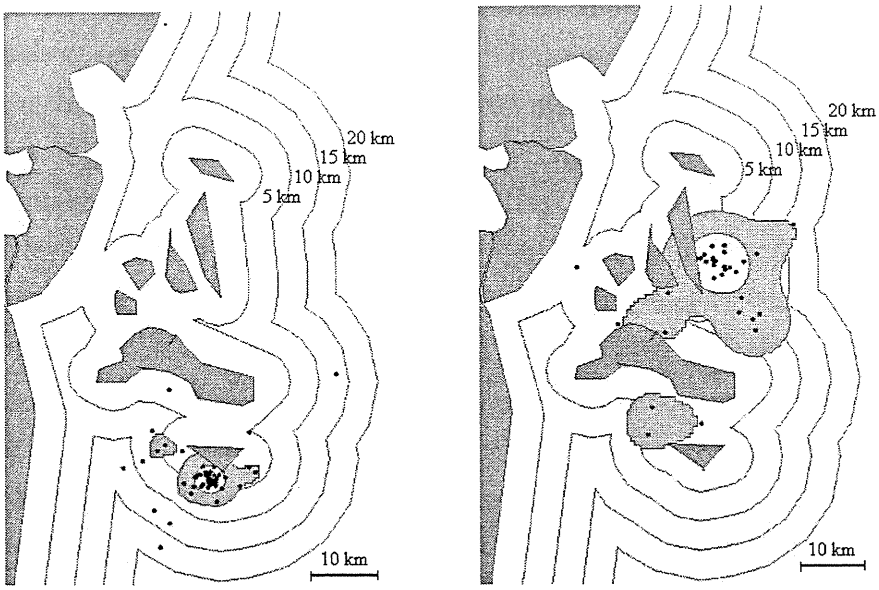


Fig. 17. A home range of ID 9780 (left) and an expanded home range of ID9784 (right). The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1.

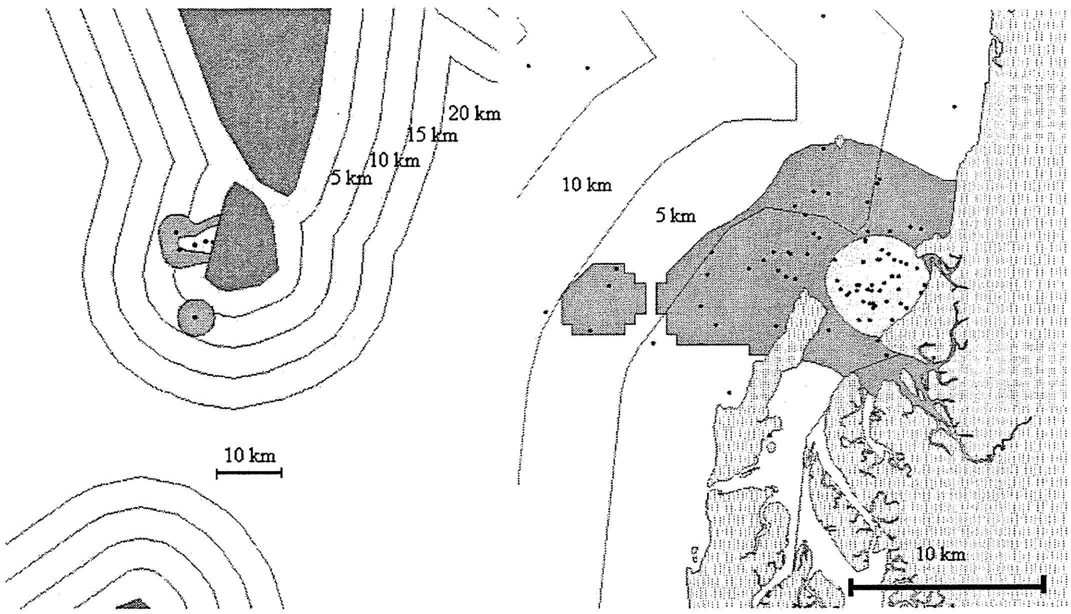


Fig. 18. A home range of ID 18683 (left) and an expanded home range of ID24438 (right). The home range was estimated using a fixed kernel density using Animal movement extension for Arc View 3.1.

The results show that female green turtles may have their feeding ground respectively and female green turtles during feeding period also do not migrate far from their feeding ground once they arrive their nesting beach. And the home ranges existed in 10 km shore buffer area. The sea grass meadows may not extended more than 10 km from the coast. This result indicated that the adequate protect area is 10 km shore buffer area form the coast. However, female turtles did not directly travel to its final destination. In this regard extended along shore movement increase the chances of turtles entering un protected coastal areas and so are likely to raise their probability of capture because the core areas of each turtle exist in the 5 km shore buffer area from the area. Shortly, in my result, the short movement along the shore included. The home range areas of green turtles during feeding period may indicate the areas of sea grass meadows. However, we cannot elucidate this hypothesis because we have to use the more intimated geographic data (e.g. remote sensing data) to confirm a turtle stay at the sea grass meadows.

Table 6. Individual number, a tracking period, a tracking duration, sample number, a home rage area of 95 % probability and a home range area of 50 % probability of female green turtles during inter-nesting period.

ID	Traking period		Duration	n	95% area (sq km)	50% area (sq km)
9730	2001/11/15	2002/1/23	69.0	57	1042.4	181.6
13062	2001/6/26	2001/10/16	112.0	176	337.6	29.3
9780	2001/10/25	2001/11/23	29.0	58	97.7	19.7
9784	2001/9/17	2001/10/14	27.0	39	270	73.7
18683	2001/9/24	2001/10/5	11.0	8	80.1	20.2
24438	2002/3/26	2002/6/9	75.0	119	152.9	22.6

Chapter 4: A new technique for a reconstruction of a three-dimensional moving path of the green turtle by cutting edge date loggers

4. 1. Introduction

A satellite tracking provide a horizontal movement and a macro scale movement of aquatic animals. However, we also to analyze a micro scale movement and a vertical movement to conserve the aquatic animals. Data logger studies enable to record the vertical movement and the micro scale movement of aquatic animals. In this chapter, I developed a new technique for an reconstruction of a three-dimensional moving path of the green turtle using cutting edge data loggers.

The green turtle (*Chelonia mydas*), listed as an endangered species on the IUCN red data book, has been recognized as a conservative species in many countries. Traditionally, to conserve the turtles, many studies were conducted on a nesting site investigation to elucidate their ecology and the biotelemetry also contributed to these studies undoubtedly. For example, long or short distance migrations between reproductive sites and feeding sites were founded using satellite telemetry in their habitats (Hays *et al.* 2001; Hatase *et al.* 2002). In the study using data loggers, Eckert *et al.* (1989) reported that leather back turtle (*Dermochelys coreacea*) dived more than 1,000 m. Recently, Minamikawa *et al.* (2000) reported that the lung air was used to achieve neutral buoyancy in loggerhead turtles (*Caretta caretta*). Although it is very important to analyze the behavior of the turtle spatiotemporally for understanding marine turtles, a recording method of a three-dimensional diving path of the sea turtles does not development. Sea turtle researchers who used data loggers depended on time-depth series data logger (Eckert *et al.* 1989; Minamikawa *et al.* 2000). But only time-depth-series data cannot result a real moving track of aquatic animal. In this paper, we introduce the new data logger to record a magnetic field and acceleration. We tried to calculate a body direction and tilt angle of the green turtles by this data logger and to illustrate a three-dimensional diving path of the turtle.

4. 2. Materials and Methods

Data loggers

To measure a three-dimensional diving path of green turtles, we developed two types of data loggers (Fig. 1). A Magneto-Resistive (MR) logger has two types of sensors, which are the MR sensor and acceleration sensor. The MR sensor records a surging and a swaying magnetic field (Fig. 2). And an acceleration sensor records a surging acceleration and a swaying acceleration (Fig. 2). The MR logger has a memory of 64 MB (5,760,000 data) and is programmed to record the data at an interval ranging from 5 ms to 1 min. The range of measurement and resolution were, respectively, ± 2 Gauss and ± 1 % FS (magnetic field) and ± 98 m/s^{-2} and ± 0.2 % FS (acceleration). The instrument was diameter 40.8 mm in diameter, 300 mm in length, and weighed 320 g in water.

A CCD logger has a color CMOS sensor to record 28,000 pixels photograph. A sampling interval is four photographs per 1 hour. The logger has a memory of 1 MB (80 photographs). A light sensor is equipped with the CCD logger only take photo in the daytime because the logger does not have a flash unit. The instrument was 92 mm in length, 40 mm in width, less than 28 mm in height, and weighed 155 g in water.

Swimming speed and depth were monitored using speed-depth-temperature (PDT) logger (UWE-200PDT; 13 g in water, 20 mm in diameter, 90 mm in length, Little Leonardo Co., Ltd), simultaneously.

Field experiments

Experiments were conducted on the nesting beach at the Huyong Island of Similan Islands (8.28°N, 97.38 °E) in the Andaman Sea from May 15 to May 31, 2003. The Huyong Island is a desert island. But it has a prior nesting beach of green turtles in the Similan Islands. The length of the nesting beach is approximately 800 m and the beach is protected by the Royal Thai Navy. All nesting turtles landed on the beach are identified by microchips inserted to their

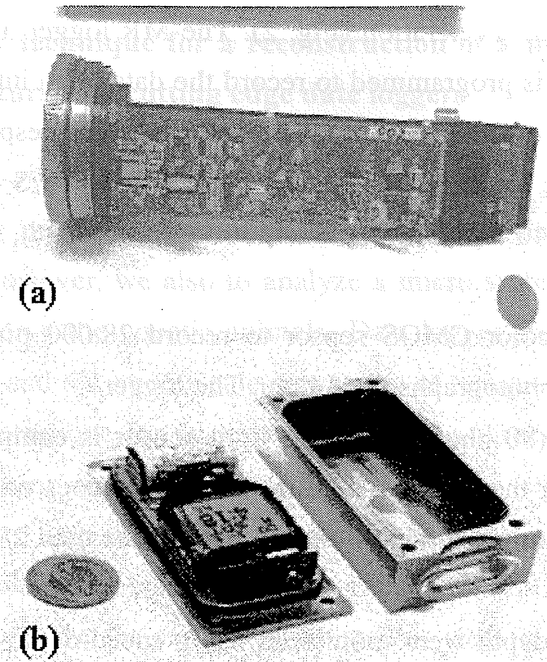


Fig.19. Photos of a MR logger and a CCD logger. The photo (a) is MR logger and the photo (b) is CCD logger.

roots of both flippers and inconel tags. Generally, green turtles lay eggs several times on same beach at approximately 2-week intervals during one breeding season. Therefore, if we attach the data loggers to a turtle at first or second nesting, we can recover the data loggers from the turtle at next nesting.

Night patrol was conducted from 8:00 PM to 4:00 AM to find female green turtles landed on the beach for nesting. The data loggers were attached on the carapace of the nesting female green turtle (Curved carapace length 100.0 cm) after the turtle laid eggs. First we attached two wooden pedestals on the carapace of the turtle using epoxy resin. We used the pedestals to attach the MR logger parallel to body axis of the turtle, and the pedestals played a role as float. Second, the MR logger (sampling frequency 10 Hz) was attached on the pedestals using cable ties. The PDT logger (sampling frequency 1 Hz) was attached beside the MR logger using epoxy resin. The CCD logger was attached on the front of carapace of the turtle using epoxy resin. We obtained the data from the turtle when the turtle subsequently returned to the beach.

Body direction

Fig. 3 shows normalized outputs of the MR sensor. The normalized outputs were ranged from –100 to 100. When the sensor was held horizontally and was rotated clockwise from the north direction, responses of the surging and swaying magnetic field recorded by the MR sensor showed the cosine (surging) and sine (swaying) functions. We calculated the horizontal body direction (θ_1) using this relationship between surging magnetic field (x) and swaying magnetic field (y) as the following Equation 1.

$$\theta_1 = \begin{cases} 90 & (x = 0, y > 0) \\ 270 & (x = 0, y < 0) \\ 180 + \mathrm{atan}(y / x) * 180 / \pi & (x < 0) \\ \mathrm{atan}(y / x) * 180 / \pi & (x > 0, y > 0) \\ 360 + \mathrm{atan}(y / x) * 180 / \pi & (x > 0, y < 0) \end{cases} \quad (1)$$

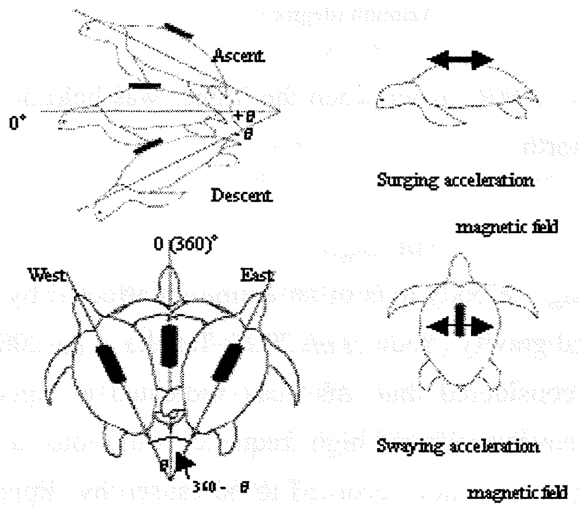


Fig.20. Schematic diagram showing the direction of surging and swaying geomagnetic and acceleration recorded by a data logger on the carapace of a green turtle (black bar). Data for surging acceleration were converted to tilt angles. Data for surging and swaying geomagnetic were converted to body directions.

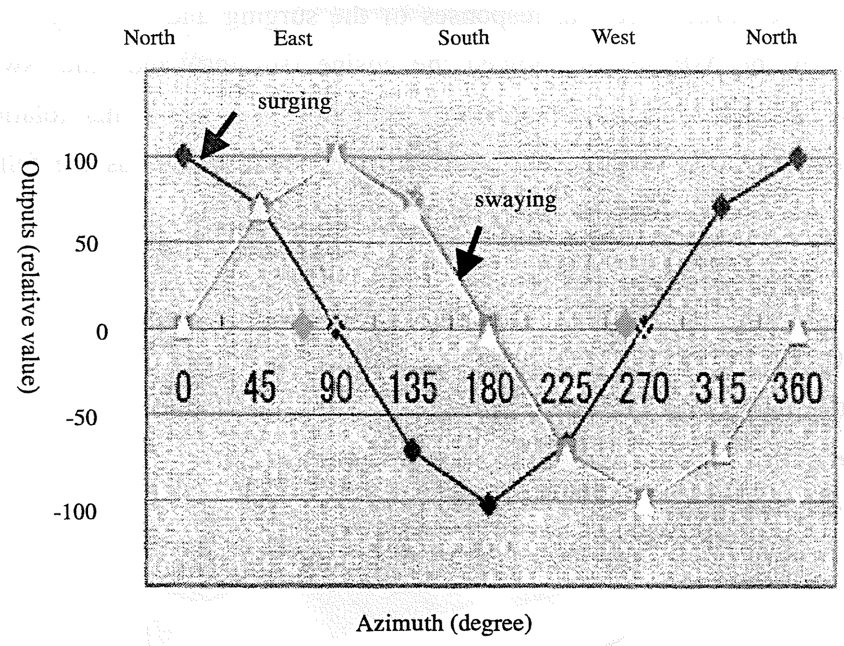


Fig. 21. Normalized outputs of MR logger when the logger was held horizontally and rotated clockwise from the north.

Tilt angle

The acceleration sensor along the body axis of an animal is affected by both forward movement s of an animal and gravity (Yoda *et al.* 2001; Tanaka *et al.* 2001). We found the peak at 0.36 Hz. We considered that this peak indicated a flipper movement frequency of the turtle. Moreover, we found high frequency variations ranged from 0.2 Hz to 0.4 Hz in the surging acceleration recorded to be caused by flipper movement. These frequencies were filtered out using a 0.2 Hz low pass filter (IFDL Version 3.1; Wave Metrics, Inc., USA; Tanaka *et al.* 2001) to get the tilt angle. When the animal is still or moving at constant speed, the gravity vector (g = 9.8 ms^{-2}) will change in response to the tilt angle (Tanaka *et al.* 2001). Therefore, we calculated tilt angle („$_2$) of the turtle using lowpass filtered surging acceleration (A) as the flowing Equation 2.

$$\theta_2 = \text{asin}(A/g) \qquad (2)$$

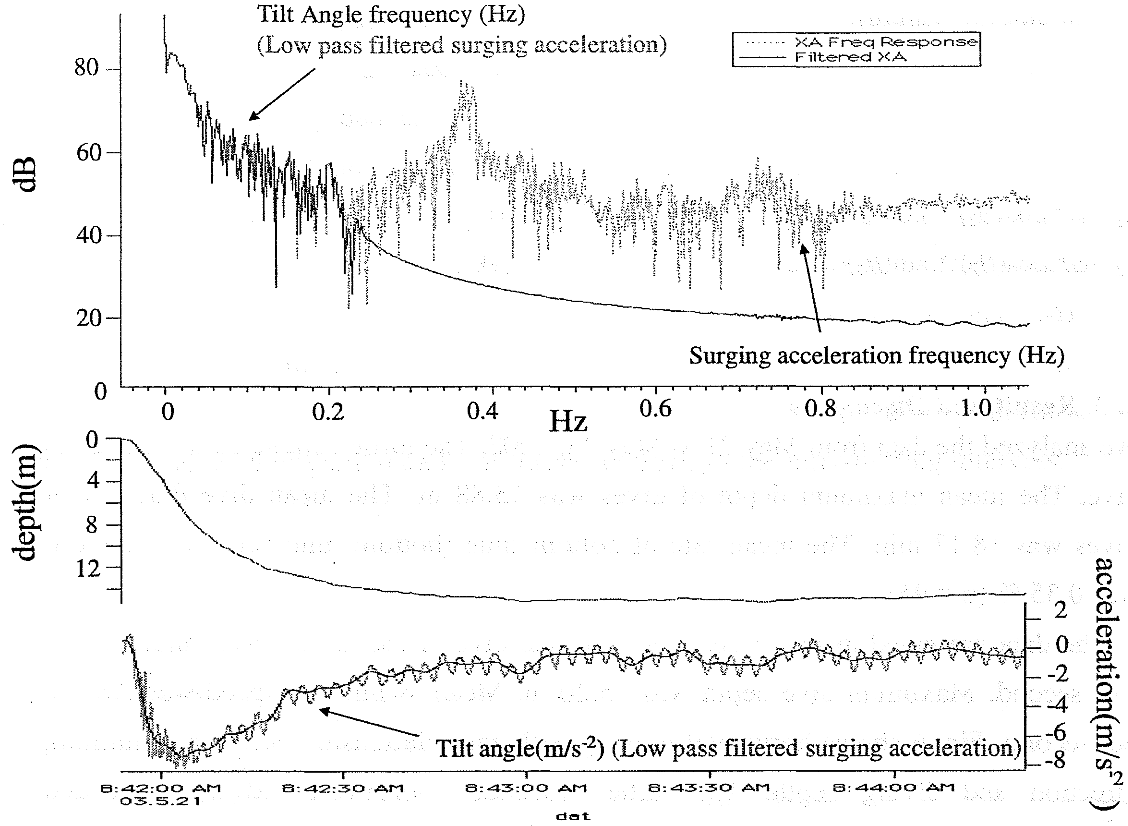


Fig. 22. Frequency response and expanded time-series of surging accelerations of the turtle for a typical diving. The Upper graph shows frequency response of surging acceleration and low pass filtered surging acceleration. The lower graph shows expanded time-series of depth, surging acceleration and low pass filtered surging acceleration, which showed tilt angle of the turtle.

We tried to attach the MR logger parallel to body axis of the turtle using the two wooden pedestals. However, it was difficult to put the MR logger exactly parallel to the body axis of the turtle. Therefore, it was necessary to correct an initial error of the tilt angle calculated from the surging accelerations. As described by Sato *et al.* (2003), initial error of the tilt angle can be corrected by the comparison between a dive profile measured by depth sensor and calculated dive profile by several adjustment tilt angle. Therefore, we corrected the initial error of the tilt angle by this method.

Horizontal moving paths

Horizontal moving paths of the turtle, which are longitudinal moving distance (d_1) and latitudinal moving distance (d_2), was calculated from the body direction („$_1$), tilt angle („$_2$) and swimming speed („) by Equation 3 (longitudinal movement) and Equation 4 (latitudinal movement).

$$d_1 = v * \cos(\theta_2) * \cos(\theta_1) \quad (3)$$
$$d_2 = v * \cos(\theta_2) * \sin(\theta_1) \quad (4)$$

4. 3. Result and Discussion

We analyzed the data from May 21 to May 23, 2003. The turtle conducted a continuous dive. The mean maximum depth of dives was 13.88 m. The mean dive duration of dives was 18.17 min. The mean rate of bottom time (bottom time per dive duration) was 0.35 % (n = 95).

The data presented in Fig. 5 describe a typical dive of the turtle. Dive duration was 710 second. Maximum dive depth was 15.20 m. Mean swimming speed was 0.81 m per second. Fig. 6 shows horizontal moving path and relationship between swimming direction and diving depth. The turtle descended northwestward and ascended southwestward during this dive. The turtle maintain its direction relatively constant during this dive. Therefore, we illustrated the three-dimensional diving path of the turtle by direction and swimming speed data (Fig. 7). However, the illustrated moving path of the turtle may be affected by ocean current because the PDT logger measured a swimming speed using propeller. Therefore, an estimating error that could affect the accuracy of the calculation of the turtle was accumulated in the moving path. Davis *et al.* (2001) and Mitani *et al.* (2003) adjusted the accumulation of the errors of the three-dimensional diving path of seals using "dead reckoning" methods. However, we cannot apply this method to adjust the accumulation of errors because a start position of dive of sea turtles differs from a goal position of the dive. To adjust the accumulation of errors of the diving track, it is very important to get positional information of diving turtle. Now we are developing the Argos transmitter equipped with GPS sensor for sea turtle study. So we will adjust the accumulation error of diving path of the turtle using GPS position in the near future.

Three-dimensional analysis by the MR logger will gratefully contribute to the studies on behavior of sea turtles. For example, we know that a sea turtle lay eggs on the beach and migrate between the fixed feeding area and fixed nesting area. However, the ability to find the nesting beach and feeding area is still unknown. A body direction of the turtle measured by the MR logger will contribute to elucidate this ability.

Traditionally, migration paths of sea turtles were studied using satellite telemetry (Hays *et al.* 2001; Hays *et al.* 2002; Hatase *et al.* 2002). However, when detailed aspects of satellite tracking data are considered, such as speed of travel and small-scale movements of sea turtles, then location accuracy is likely to become a important issue (Hays *et al.* 2001). In sea turtle study, a high proportion of locations may be of low quality because a signal from a transmitter uplinks to the satellite when a turtle swim at sea surface only. The MR logger tracking will become a solution for this problem. MR logger can track a migration path of the turtle continuously. A recording time of the MR loggers, however, are limited due to their battery. Therefore, our future plan for is to track more detailed migration paths of turtles all through the inter-nesting intervals.

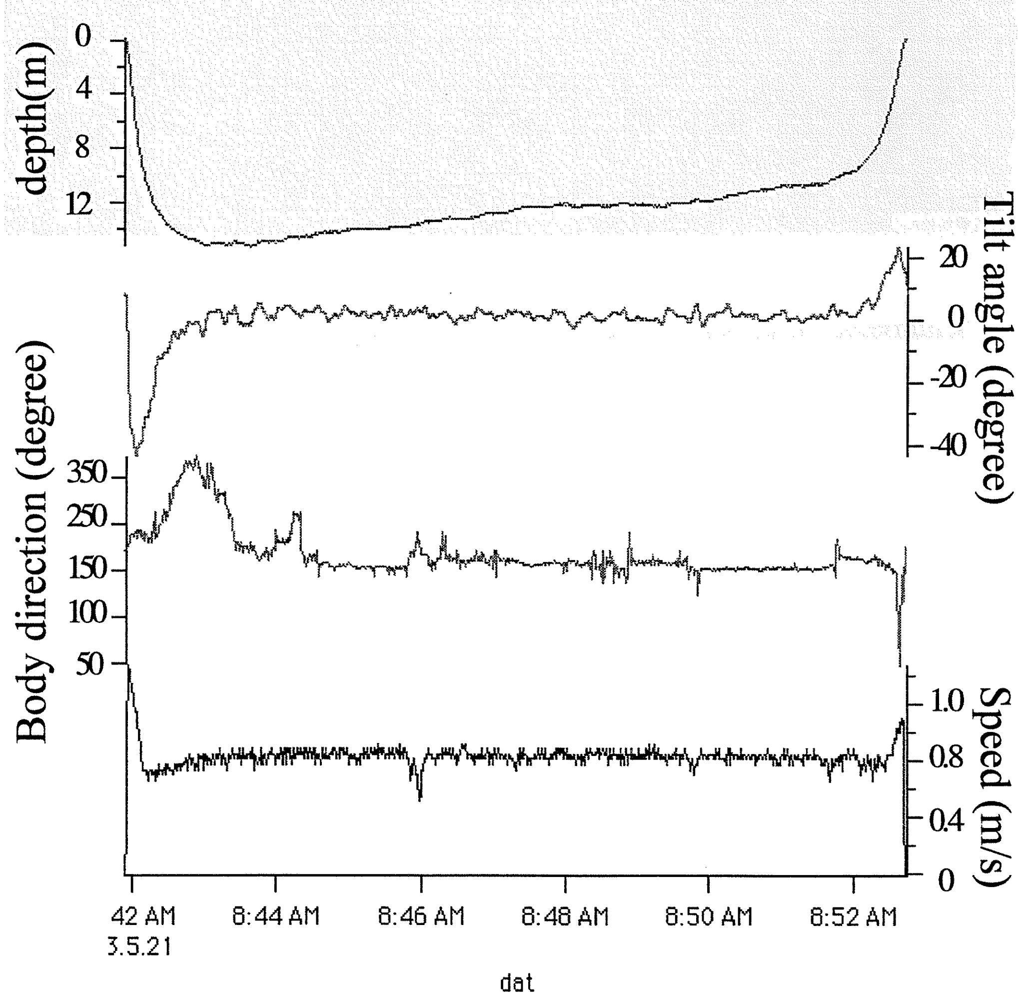


Fig. 23. Expanded time-series of depth, tilt angle, body direction and swimming speed for typical 1 dive of the turtle.

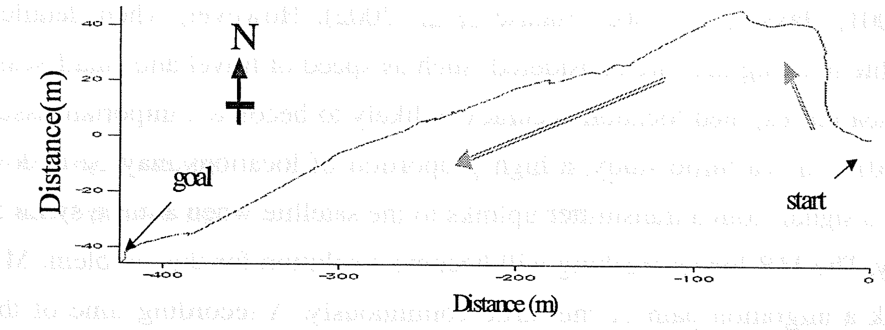


Fig. 24. Horizontal moving path for typical 1 dive of the turtle determined by the body directions and swimming speeds

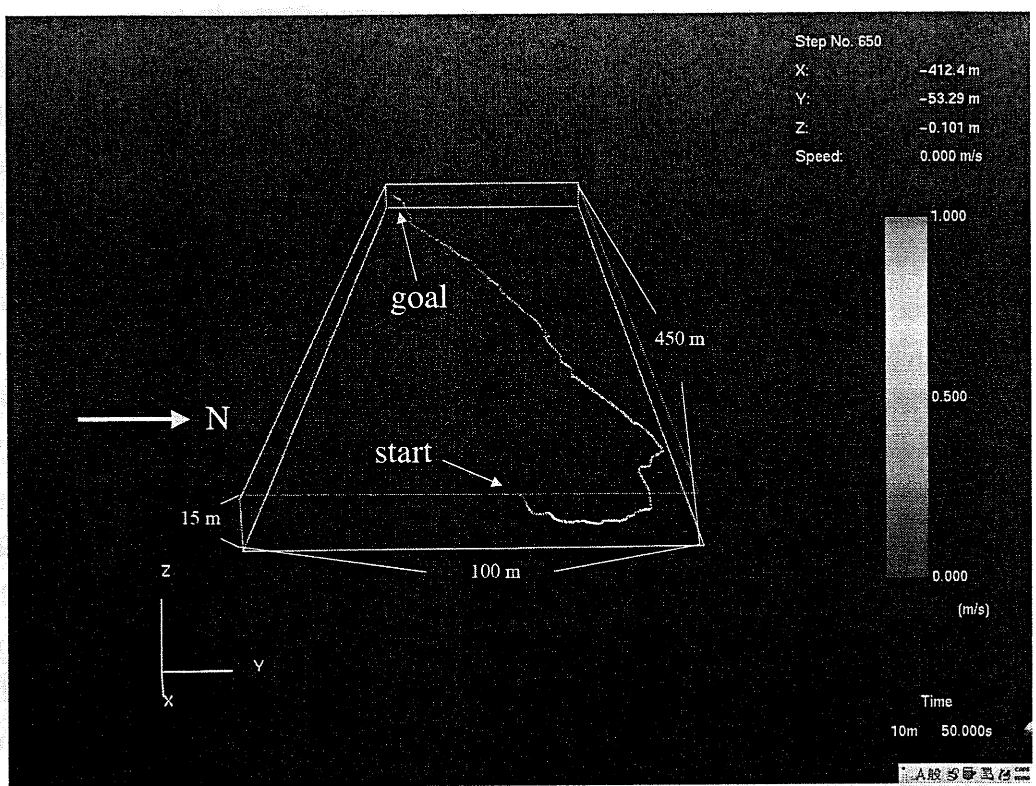


Fig . 25. Three-dimensional moving paths for typical 1 dive of the turtle determined by the body directions, tilt angles and swimming speeds.

Chapter 5: Discussions

A one of the threats that sea turtles are confronted is incidental catch by shrimp trawl fisheries. A technological solution to separate turtles from shrimp trawl net was available by early 1980s. A Turtle Excluder Device (TED) incorporates a trap door in the trawl, just before the cod-end, to allow sea turtles to escape from the nets (Siedel and McVea, 1982). The TED probably decreases the mortality of the adult turtles and increases the breeding rate. The other threat is lowness of survival rates of juveniles and hatchlings. Almost past conservation programs are concentrated to increase the survival rate of juveniles and hatchlings (Crowder et al., 1994)). They reported that TED is more effective compared to the past conservation programs. But we consider that the TED is not effective in Gulf of Thailand, because the habitats of the green turtles differ from the shrimp trawl fishing grounds vertically and horizontally. We will have to research about other areas and other species continuously.

In chapter 3, I tracked migration paths of female green turtles nested in Huyong Island in the Andaman Sea. The results of satellite tracking study show that female green turtles migrated from the Huyong Island, Thailand to the Andaman Islands, India. The Andaman Islands are provably feeding grounds of female green turtles nested in the Huyong Island. And the results show that they straddled the EEZ of some countries (Thailand, India and Myanmar). It indicates that cooperation among relational countries is needed to conserve this population. In This chapter, I estimated the home range areas of the female green turtles during inter-nesting period and feeding period. The home range area of female green turtles during inter-nesting interval was 107.7 square kilometer and the core area was 21.2 squarer kilometer (n = 300; 5 turtles). And this home range area included a 7 km shore buffer area. This result shows that a legitimate marine protect area for a conservation of the nesting females is the 7 km shore buffer area. The results of home range analysis in the feeding ground indicated that female green turtles have their feeding ground respectively and they do not migrated far from their feeding ground once they arrived there. These home range areas may indicate the sea grass meadows. Because the home ranges existed in 10 km shore buffer and core areas existed in 5 km shore buffer. It indicated that turtles use shallow waters as habitat. However, we have to use more intimated geographic information to confirm this hypothesis. Remote sensing data was very utility data for this analysis. Therefore, the future plans of this study is to adapt the remote sensing data to elucidate the habitat use of the green turtle in the feeding ground.

In chapter 4, I develop a new method for a reconstructing a moving path of the green turtle using data loggers. A satellite tracking provide a horizontal movement and a macro scale movement of aquatic animals. However, we also have to analyze a micro pattern and a vertical movement of aquatic animal to conserve them. Three-dimensional moving paths of the green turtle were reconstructed by a MR logger and a PDT logger. However, the reconstructed paths may be affected by environmental effects (e.g. ocean current) because the PDT logger measured a swimming speed using propeller. Therefore, an estimating error that could affect the accuracy of the calculation of the turtle was accumulated in the moving path. To adjust the accumulation of errors of the diving track, it is very important to get positional information of the diving turtle.

Three-dimensional analysis by the MR logger will gratefully contribute to the studies on behavior of the sea turtle. For example, sea turtles are known to migrate between fixed nesting sites and fixed feeding grounds. However, the ability to find the nesting beach and feeding areas is still unknown. A body direction of the turtle measured by the MR logger will contribute to study on this ability.

Many conservation programs of a management nesting beach and eggs in Similan islands (Winai, 2002), an educational programs for local children and tourists (Aureggi, 2002) and an ecotourism in Mannai islands (Okuyama et al., 2002) are reported in the SEASTAR 2000 workshop. For example, the Phuket Marine Biological Center (PMBC) has conducted a head starting to increase the survival rate of young turtles since 2002. The PMBC has released 300 juvenile inserted microchips to their flippers from the Similan islands. Ecotourism is expected as a one of sustainable conservation programs recently. In SEASTAR2000, Okuyama et al. (2002) have begun to research since 2002 for tourists to Mannai Islands. New conservation programs that are ecotourism and head starting are expected to increase conservation effect and to realize sustainable conservation. But there are very few successful examples of the new conservation programs, because many studies neglect local cultural background and the ecology of sea turtles, i.e. consumptive use of sea turtles and frenzy period during hatchlings. It is consider that sustainable conservation and management including consumptive use is realized by integration and harmonization of socioeconomic, cultural and scientific studies. To realize them, much information is needed, and we have to share the information effectively with relational countries and open the information to any countries and peoples using computer technologies to enhance cross-cultural communication – for example, many peoples communicate to their community members from foreign countries using database and web pages by web server and newsletters by e-mail recently. And we have to use the results of SEASTAR2000 effectively for the conservation programs. For example, If we construct the marine protect areas of green turtles, we have to construct a harmonic protect areas between sea turtles and fisheries. The results of home range analysis showed that a legitimate marine protect area of green turtles was 6 km shore buffer area in Huyong Island. The results show that female green turtles may have their feeding ground respectively and female green turtles during feeding period also do not migrate far from their feeding ground once they arrive their nesting beach. And the home ranges existed in 10 km shore buffer area. The sea grass meadows may not extended more than 10 km from the coast. This result indicated that the adequate protect area is 10 km shore buffer area form the coast. However, female turtles did not directly travel to its final destination. In this regard extended along shore movement increase the chances of turtles entering un protected coastal areas and so are likely to raise their probability of capture because the core areas of each turtle exist in the 5 km shore buffer area from the area. Shortly, It means scientific data help us to construct the legitimate conservation programs.

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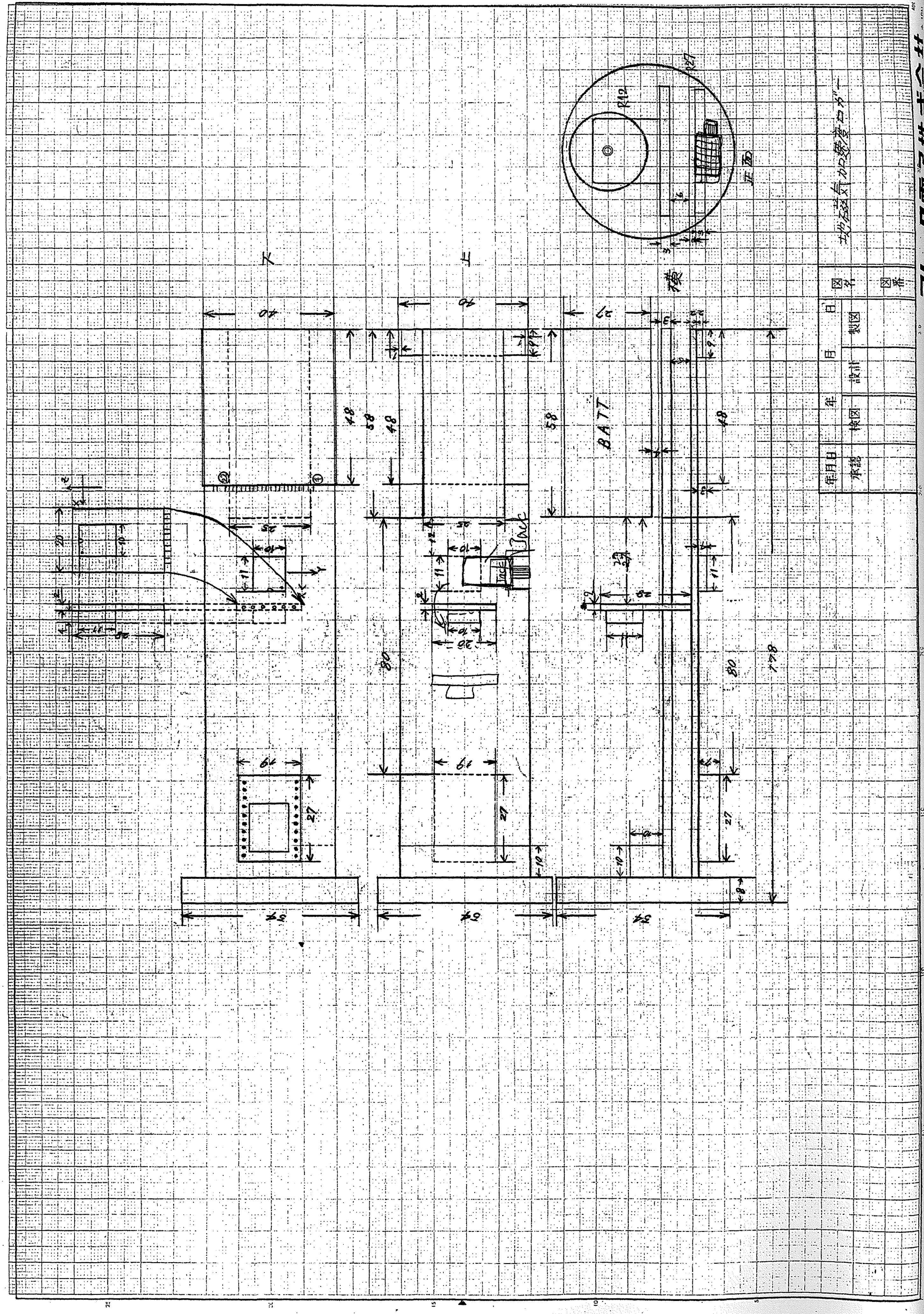
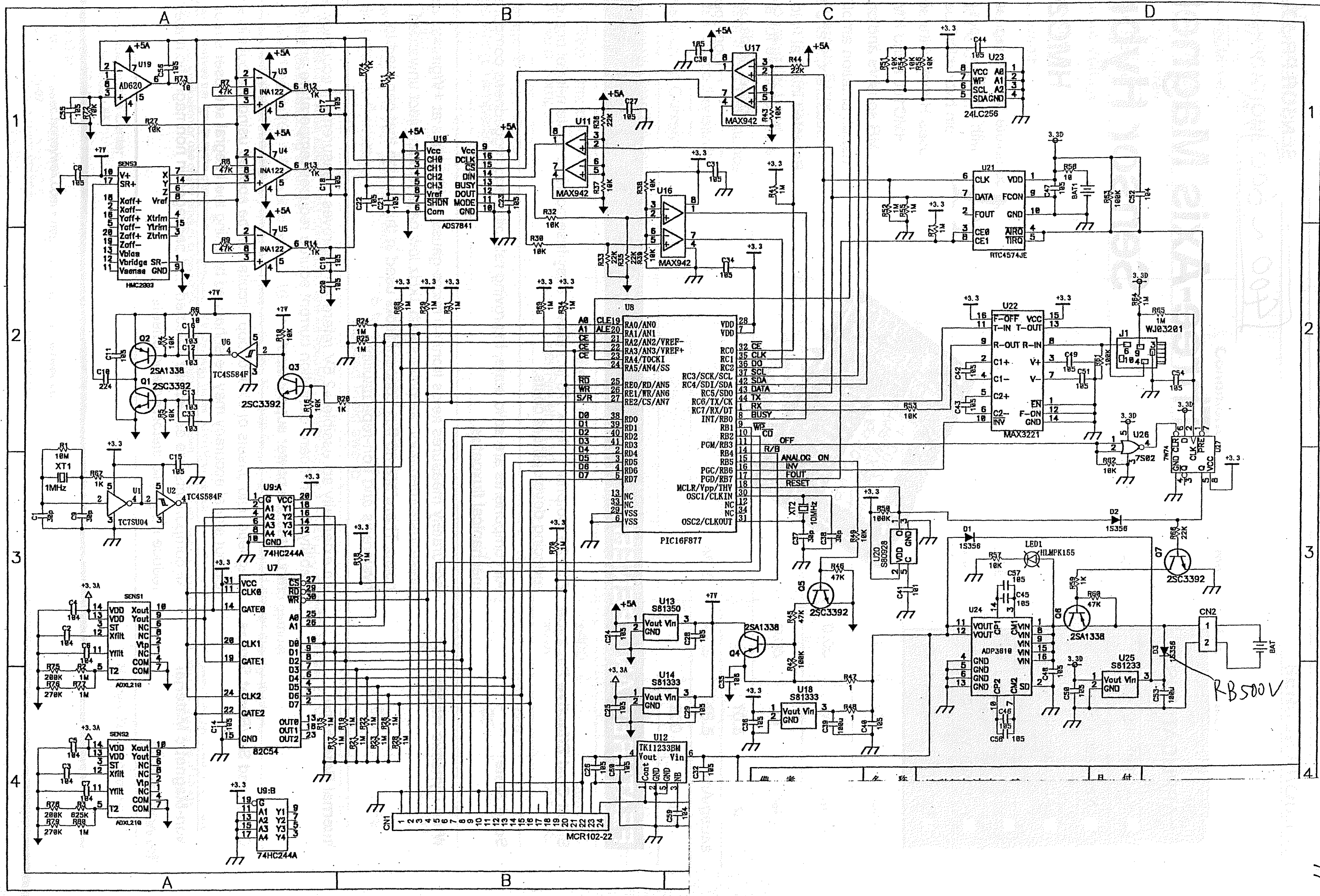
地磁気センサロガー設計図面等


BATT
R12
正面
Jack


A
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1
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AD620
INA122
ADS7841
MAX942
24LC256
RTC4574JE
HMC2003
PIC16F877
MAX3221
WJ03201
74HC244A
82C54
ADXL210
MCR102-22
TK11233BM
S81350
S81333
S81233
S80928
ADP3610
2SA1338
2SC3392
TC4S584F
TC7SU04
7S02
HLMPK155
RB500V

H13 (7 ?)

Honeywell

SENSOR PRODUCTS

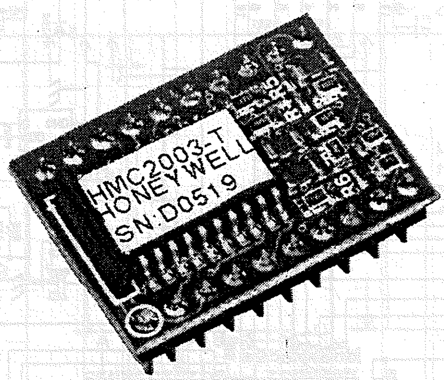
400 ~ 600 mm 50 mm

Three-Axis Magnetic Sensor Hybrid

HMC2003

APPLICATIONS

- Compassing
- Navigation Systems
- Attitude Reference
- Traffic Detection
- Proximity Detection
- Medical Devices



A complete 3-axis magnetometer with analog output in a 20-pin hybrid DIP package. Uses Honeywell's sensitive HMC1001 and HMC1002 MR sensors and precision instrumentation amplifiers to measure x, y and z axes. Patented integral field straps are accessible for applying offset fields or closed loop operation.

FEATURES AND BENEFITS

Small Cost Effective Package	DIP-20 footprint (1 in. x .75 in.) allows easy insertion into system-level boards, reducing development costs.
Solid State	All components are solid state, improving reliability and ruggedness compared to mechanical fluxgates.
Wide Dynamic Range	Accurately measures fields from 40 micro-gauss to ±2 gauss at 1V/gauss. Low noise instrumentation amplifiers with 1kHz low pass filters, reject unwanted noise. There are no flux concentrators used in this design that can lead to hysteresis and non-repeatablilty.
Internal Reference	An externally accessible +2.5V reference improves measurement accuracy and stability. An on-board excitation current source reduces temperature errors and regulates the power supply input.
Offset and Set/Reset Straps	Magnetic field offsets or closed loop circuits can be applied using the built-in straps. Output signal accuracy may be enhanced by using the integral set/reset straps.
Non-Magnetic Material	All components are especially selected and packaged in nonmagnetic material to reduce magnetic distortion and offsets.

HMC2003

SPECIFICATIONS

Characteristic	Conditions [1]	Min	Typ	Max	Units [2]
Supply Voltage [3]		6		15	VDC
Supply Current				20	mA
Field Range		-2		2	gauss
Output Voltage		0.5		4.5	V
Resolution			40		μgauss
Bandwidth			1		KHz
Field Sensitivity		0.98	1	1.02	V/gauss
Null Field Output		2.3	2.5	2.7	V
Linearity Error	±1 gauss Applied Field Sweep		0.5	2	%FS
Linearity Error	±2 gauss Applied Field Sweep		1	2	%FS
Hysteresis Error	3 sweeps across ±2 gauss		0.05	.1	%FS
Repeatability Error	3 sweeps across ±2 gauss		0.05	.1	%FS
Offset Strap Resistance				10.5	Ω
Offset Strap Sensitivity		46.5	47.5	48.5	mA/gauss
Offset Strap Current				200	mA
Set/Reset Strap Resistance				6	Ω
Field Sensitivity Tempco			-600		ppm/° C
Null Field Tempco	Set/Reset not used		±400		ppm/° C
Null Field Tempco	Set/Reset used		±100		ppm/° C
Storage Temperature		-55		125	° C
Operating Temperature		-40		85	° C
Shock			100		g
Vibration			2.2		g rms
Power Supply Effect (shifts in Null Field Offset or Sensitivity)	Power Supply varied from 6 to 15VDC with ±1 gauss Applied Field sweep			0.1	%FS

(1). Unless otherwise stated, test conditions are as follows: power supply = +12VDC, ambient temp = 25°C, Set/Reset switching is active.
(2). Units: 1 gauss (G) = 1 Oersted (in air), 1G = 79.58 A/m, 1G = 10E-4 Tesla, 1G = 10E5 gamma.
(3). Transient protection circuitry should be added across V+ and Gnd if an unregulated power supply is used.

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Plymouth, MN 55441
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900151 Rev. C 10-97

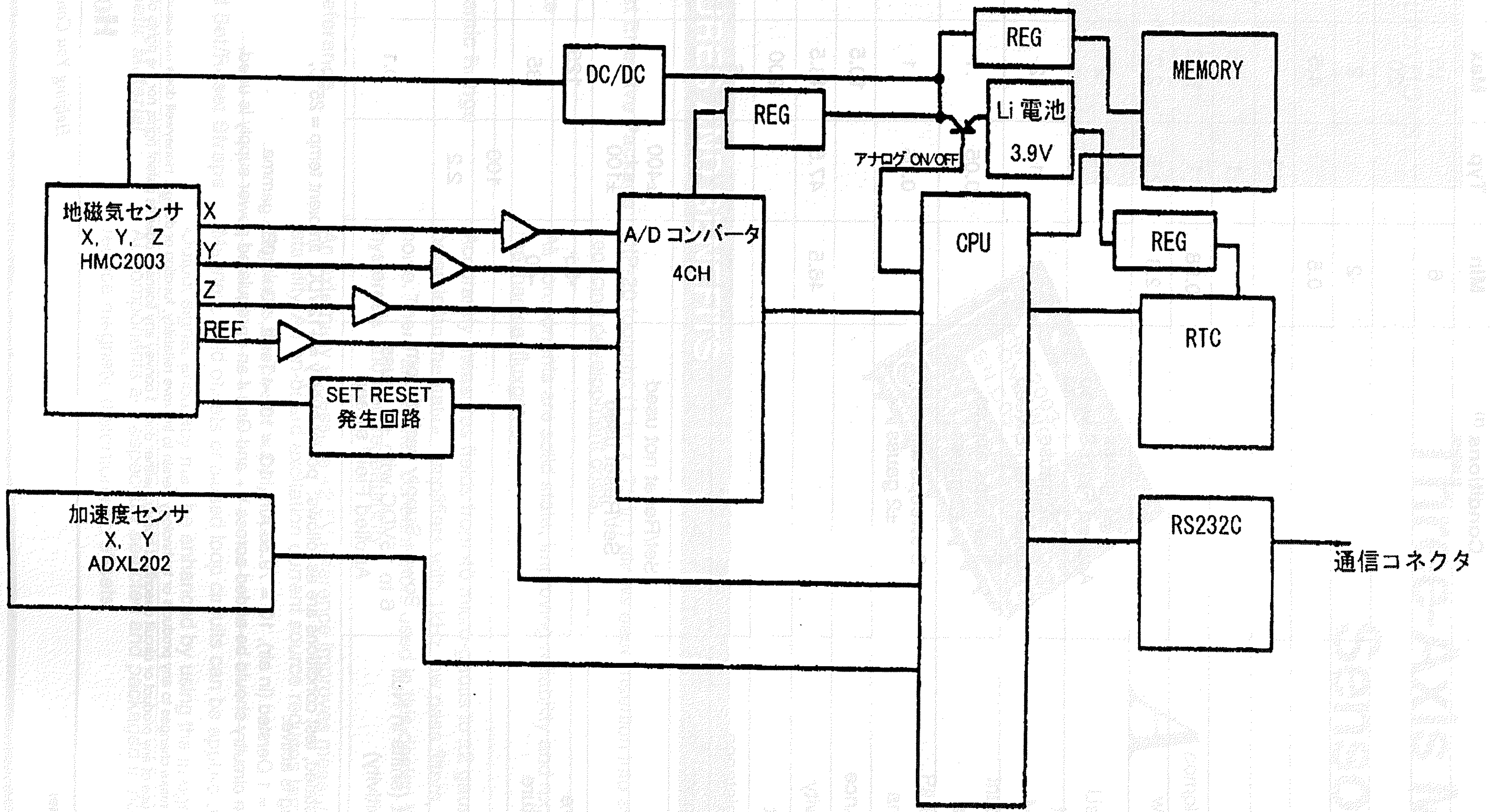

図 1. 地磁気加速度ロガーの構成図.

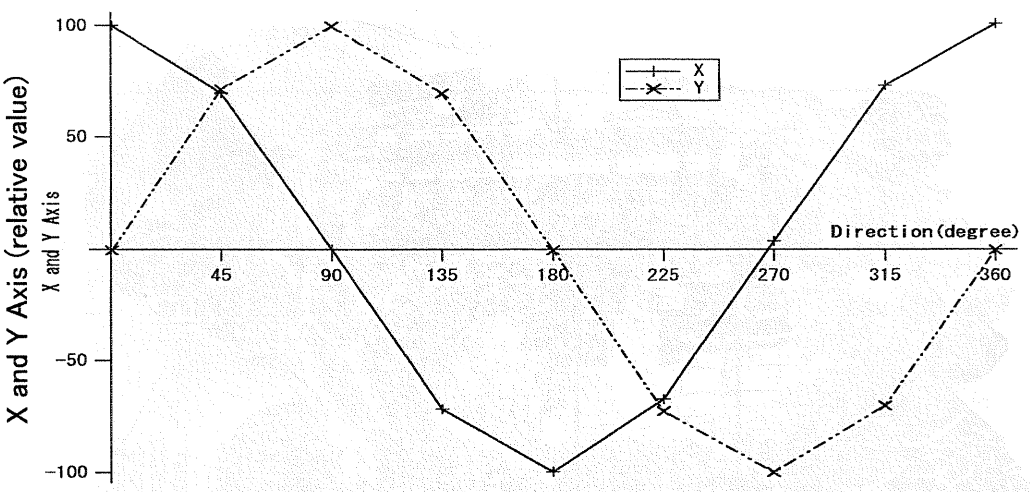

図2. ロガーを水平面で360° 回転させたときのX, Y軸の地磁気センサの出力の相対値.

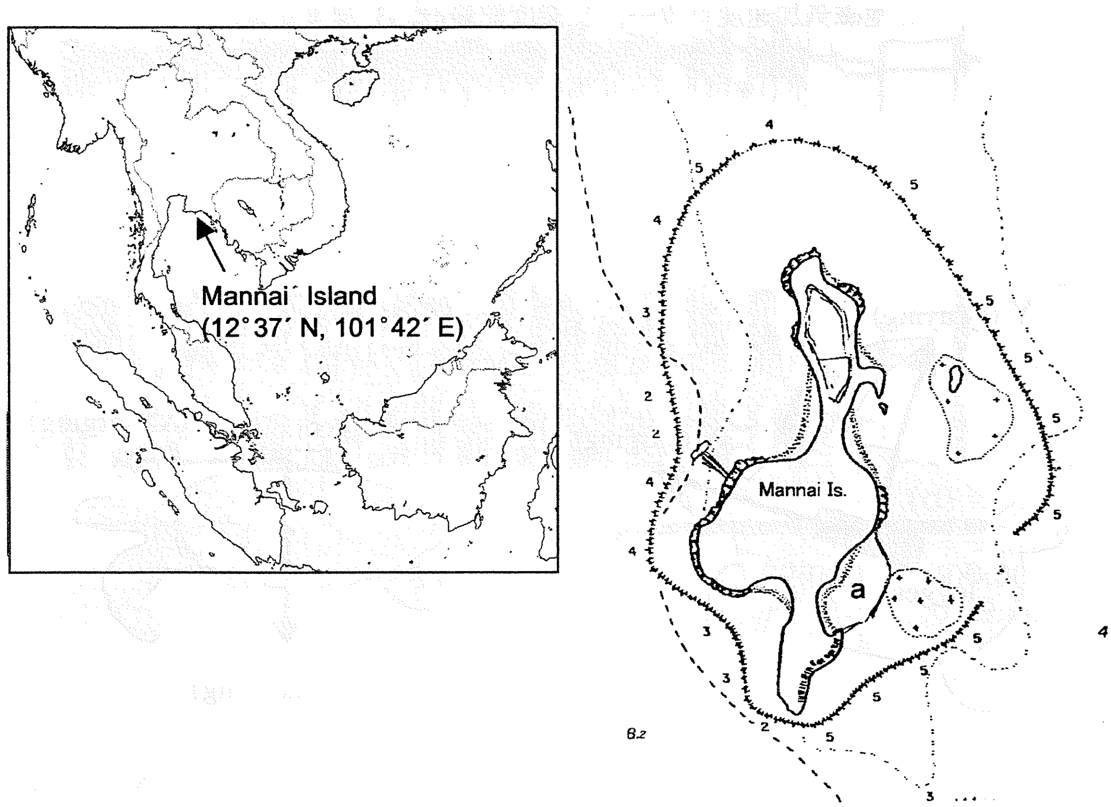

図3. 実験を行ったマンナイ島ウミガメ保護ステーション（タイ国ラヨーン県）.
a. 実験を行った飼育池.

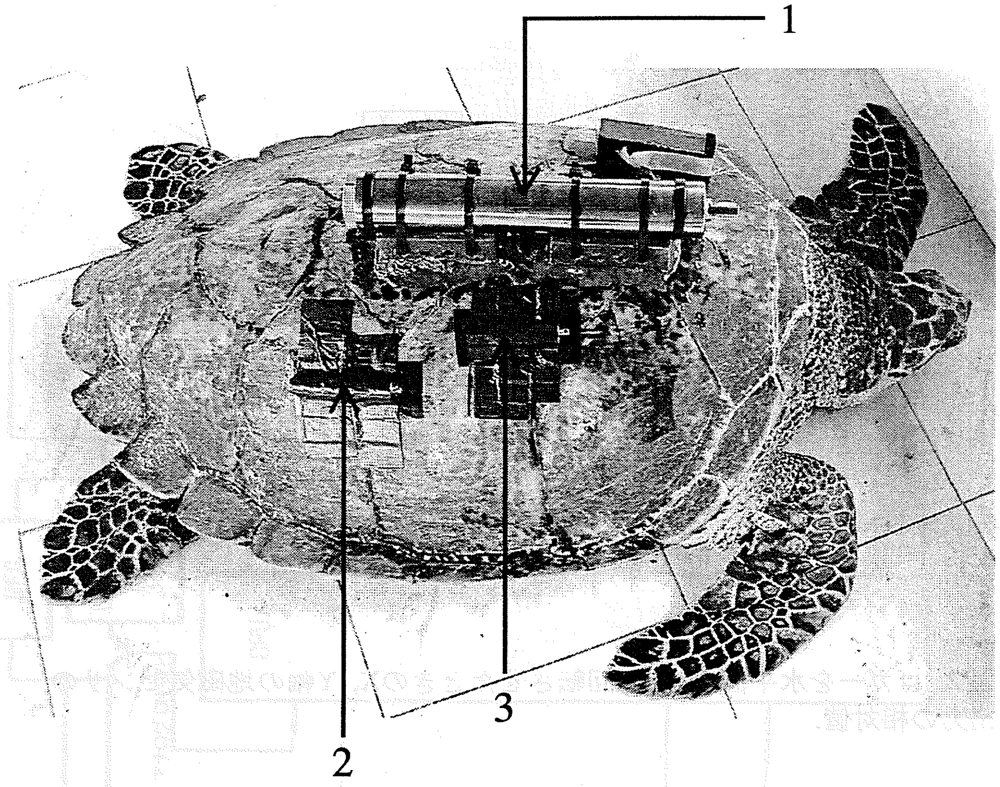

図 4.　データロガーを装着したタイマイ.
1. 地磁気加速度ロガー，2. 深度記録計，3. 温度記録計

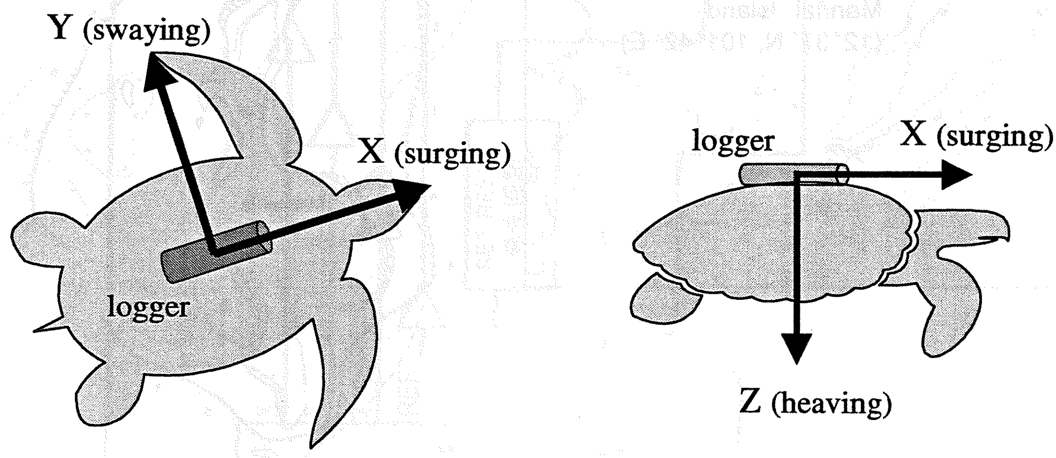

図 5.　地磁気加速度ロガーの各測定軸の方向．地磁気はX，Y，Zの3軸方向，加速度はX，Yの2軸方向をそれぞれ測定した.

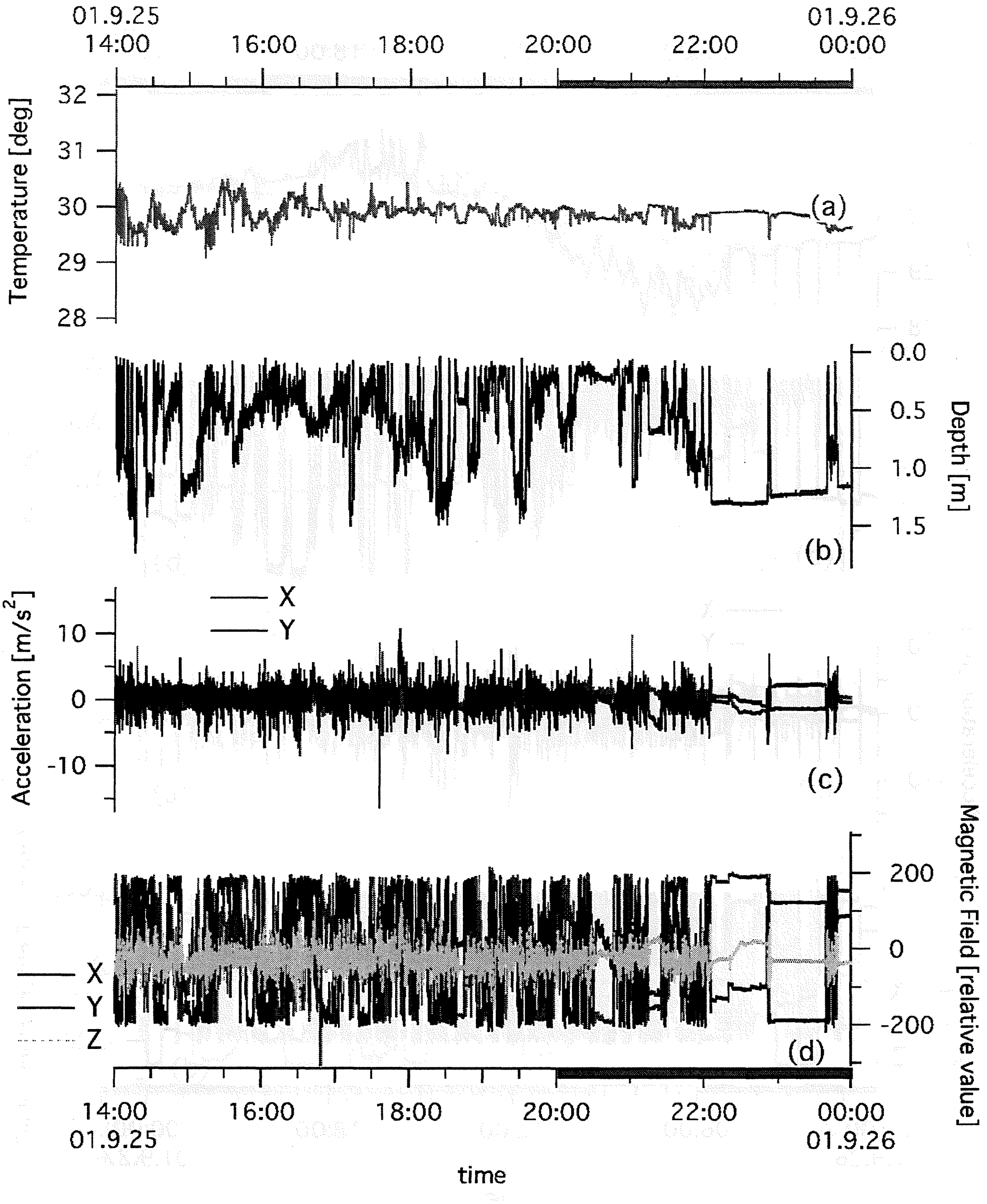

図 6-1. データロガーによって得られた記録.
HB-1の9月25日14:00の放流後から9月26日0:00までのデータ.
a）水温，b）遊泳深度，c）加速度，d）地磁気.
横軸の黒で塗りつぶした部分（20:00-0:00）は夜間を表す.

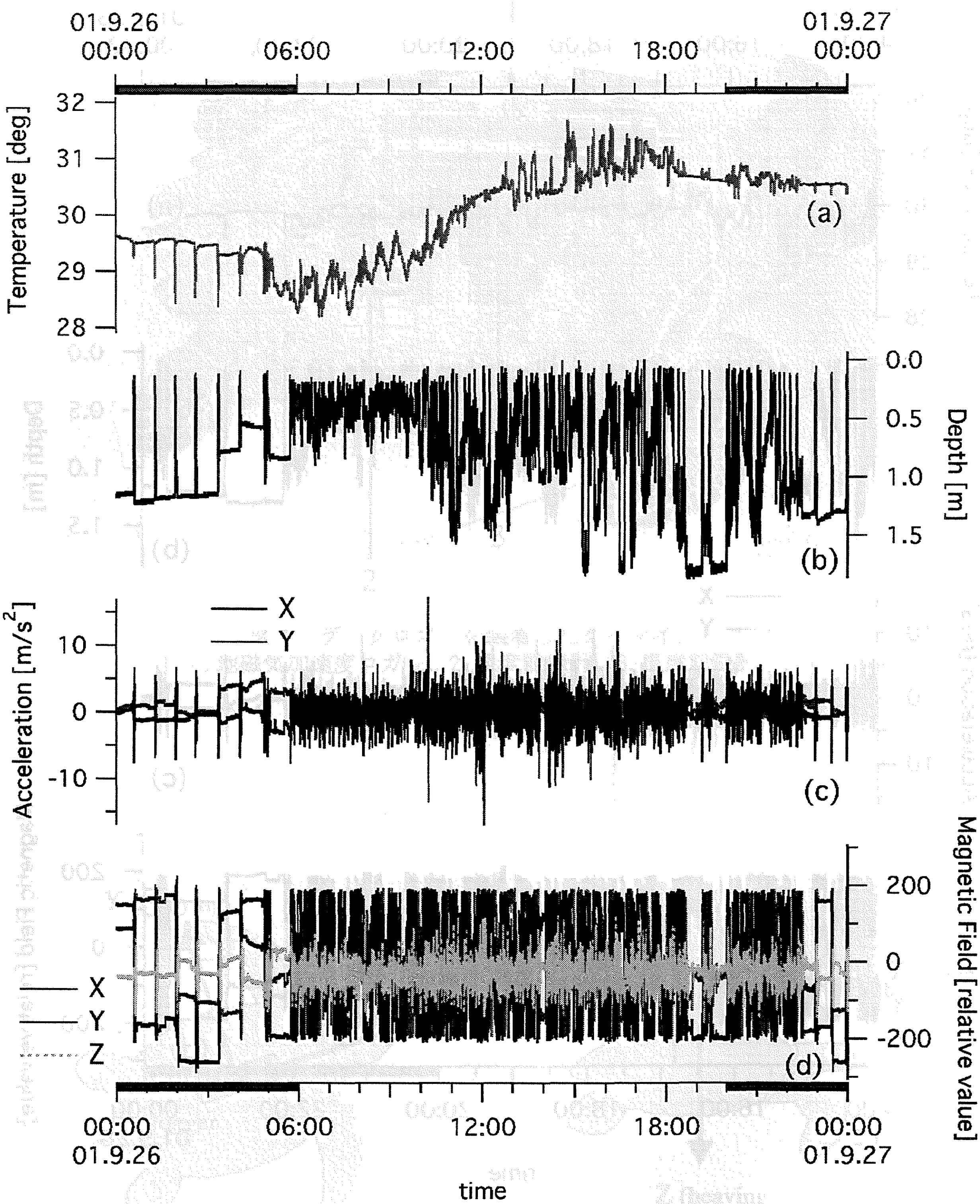

図 6-2. データロガーによって得られた記録.
HB-1の9月26日0:00から9月27日0:00までのデータ.
a）水温，b）遊泳深度，c）加速度，d）地磁気.
横軸の黒で塗りつぶした部分（0:00-6:00, 20:00-0:00）は夜間を表す.

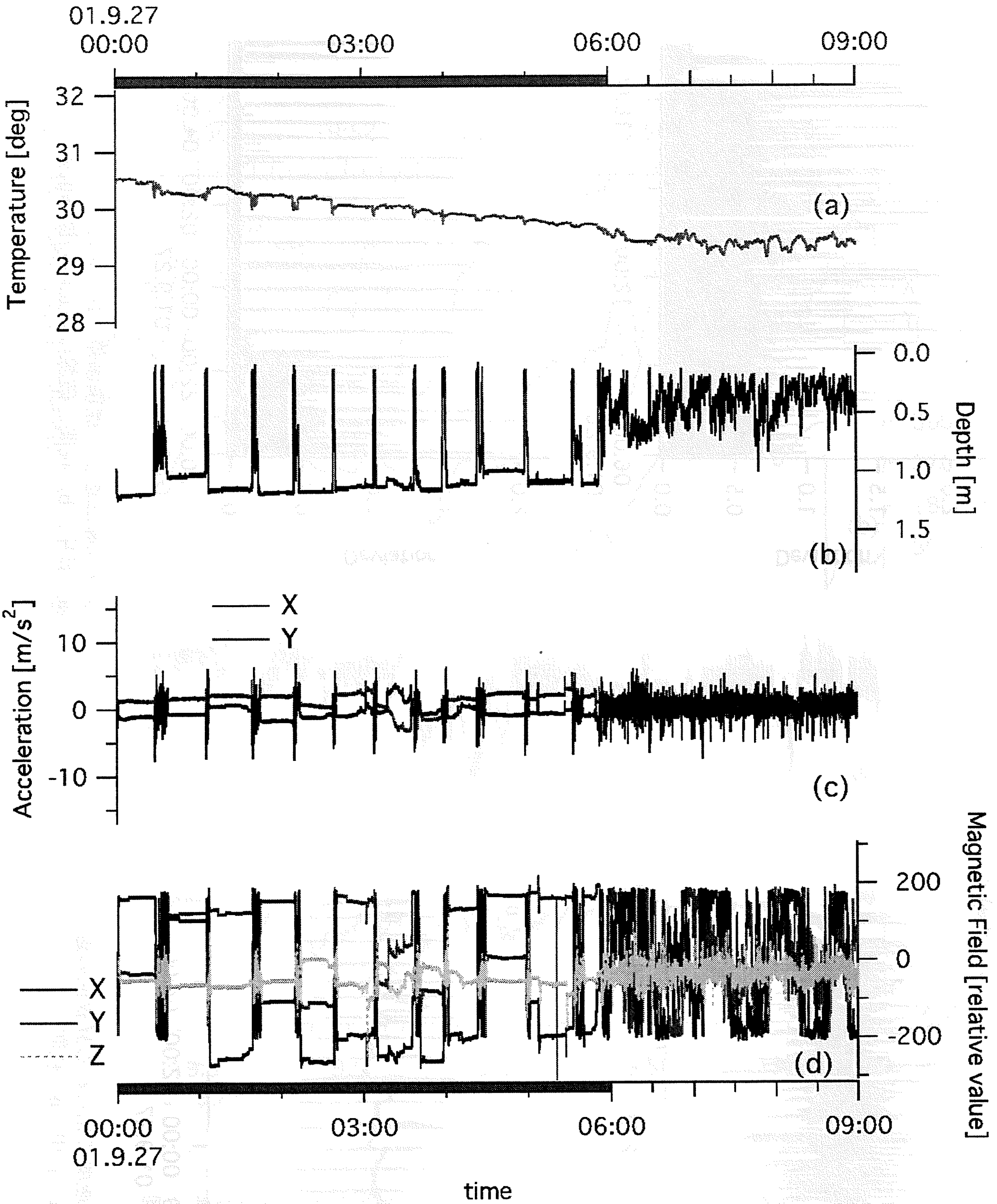

図 6-3. データロガーによって得られた記録.
HB-1の9月27日0:00から9月27日9:00までのデータ.
a）水温，b）遊泳深度，c）加速度，d）地磁気.
横軸の黒で塗りつぶした部分（0:00-6:00）は夜間を表す.

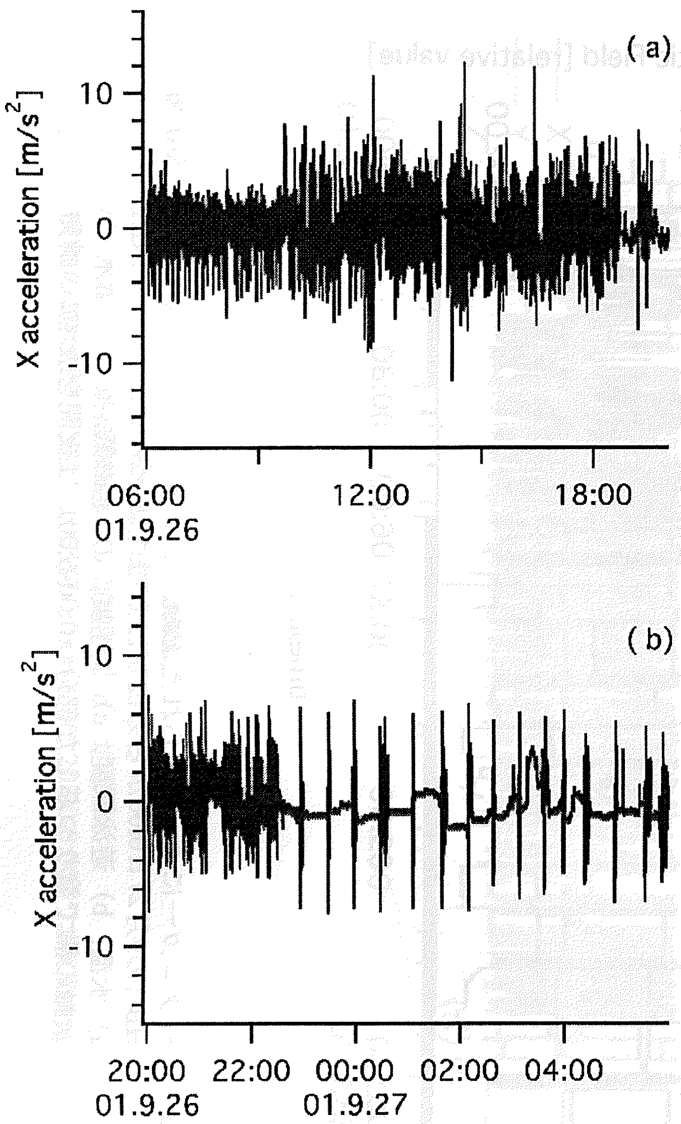

図 7. 加速度に見られる昼夜間の違い.
a）日中，b）夜間.

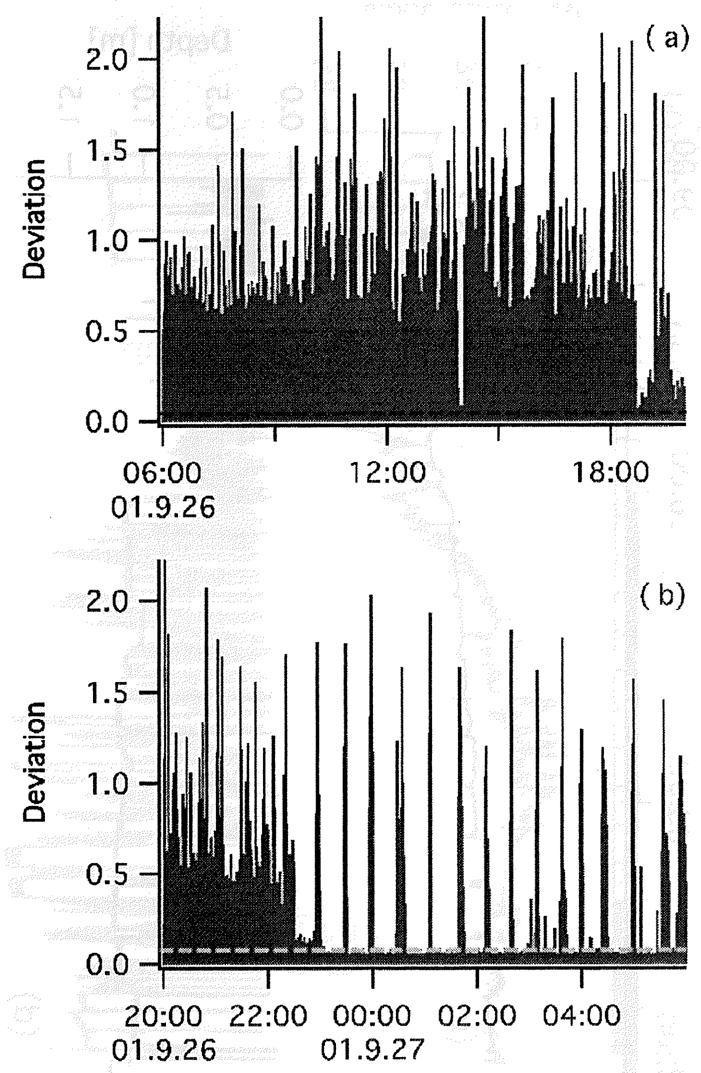

図 8. X軸加速度の標準偏差（N=40）.
a）日中，b）夜間．破線は静止時の標準偏差（0.07）を示す.

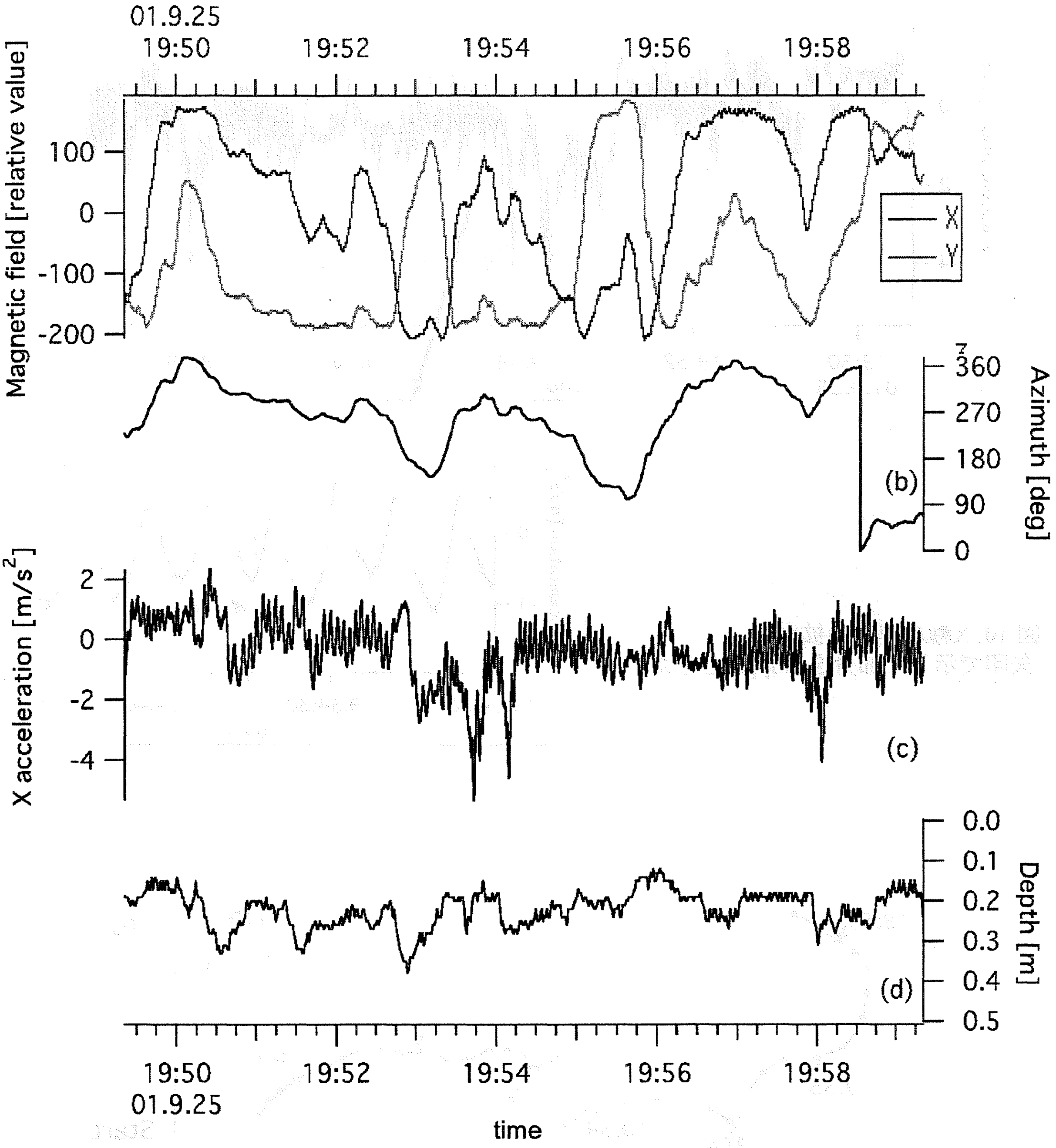

図 9. 地磁気データからの方向決定．a）地磁気データ（X，Y軸），b）計算された方位，c）加速度データ（X軸），d）遊泳深度．

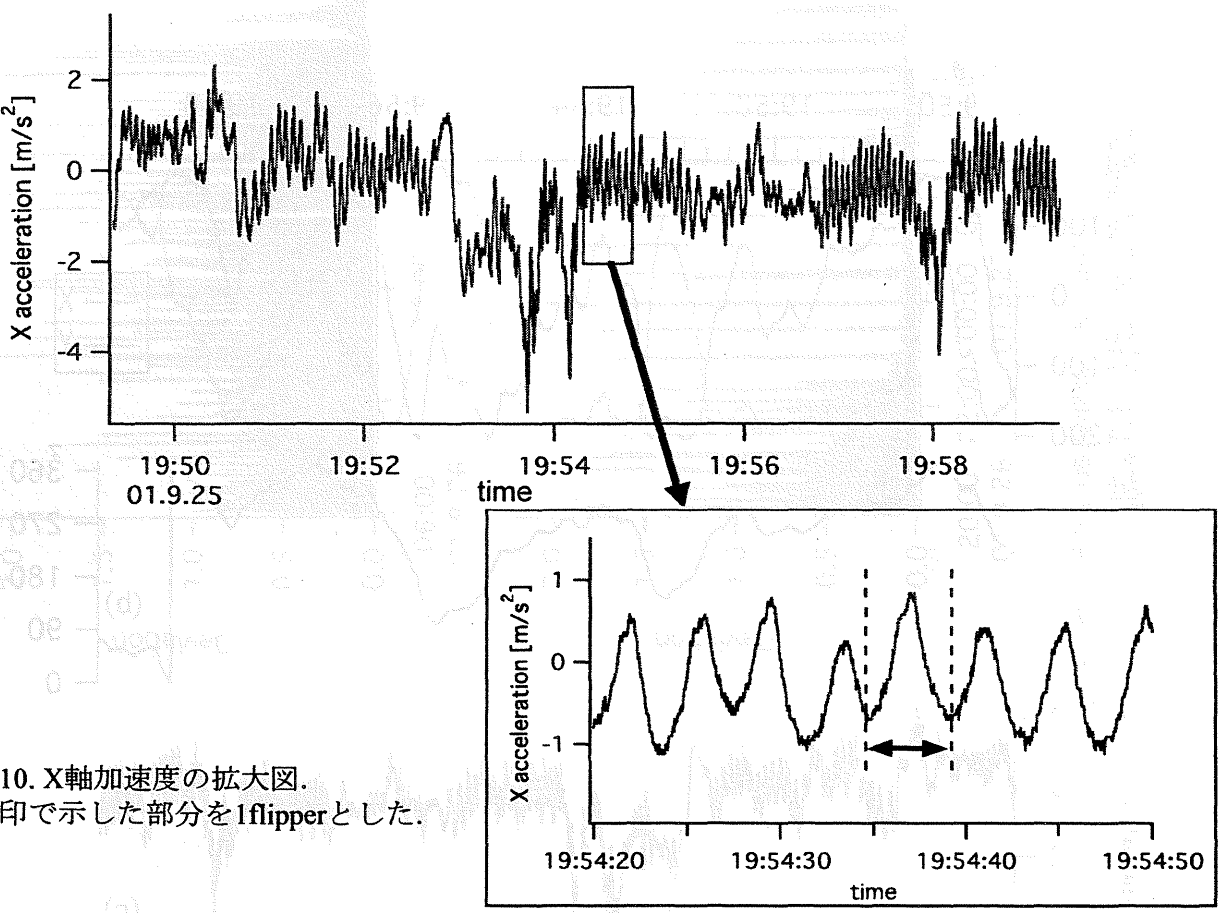

図 10. X軸加速度の拡大図.
矢印で示した部分を1flipperとした.

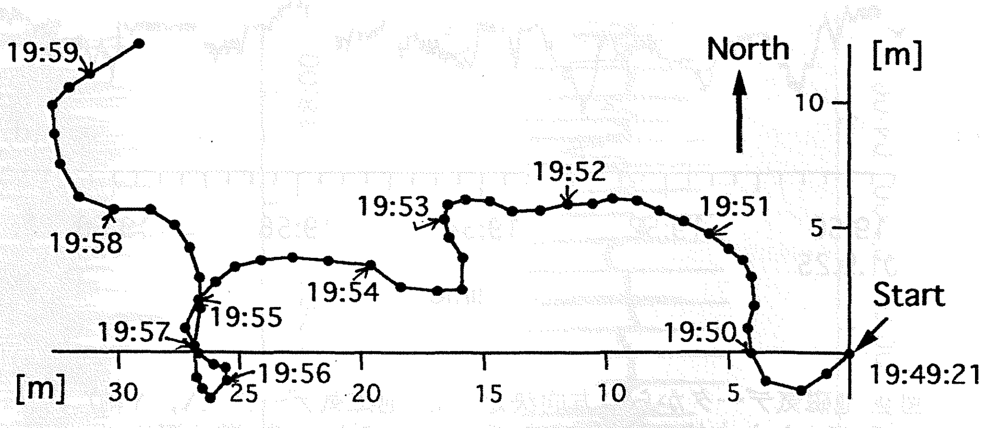

図 11. 1flipperあたりの遊泳距離を0.5mと仮定して再現したHB-1の遊泳経路.
黒丸（・）は10秒ごとの地点を示す.